Ecosystem functioning, ecosystem services and rooibos production as affected by connectivity to natural vegetation and agrochemical use in rooibos tea (*Aspalathus linearis*) farming

Presented by

Mariantѐ Herbst

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Supervisor: Prof Michael D Cramer[1]

Co-supervisors: Dr Heidi-J Hawkins[1, 2] and Dr Colleen L Seymour[3]

[1] Department of Botany, University of Cape Town, South Africa, michael.cramer@uct.ac.za
[2] Conservation South Africa, South Africa, h.hawkins@conservation.org, Heidi-jayne.hawkins@uct.ac.za
[3]South African National Biodiversity Institute, South Africa, c.seymour@sanbi.org.za

Declaration

I, Marianté Herbst, declare that the thesis/dissertation, which I hereby submit for the degree MAGISTER SCIENTIAE (Botany) at the University of Cape Town, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution. I know the meaning of Plagiarism and declare that all of the work in the document, save for that which is properly acknowledged, is my own.

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General abstract

Globally, increasing land-use intensity has led to more intensive farming practices at the local scale and the loss of non-crop habitats at the landscape scale which may affect various ecosystem services. Insect pollination by wild pollinators is especially affected, but their relative impact and possible interactions have been relatively unexplored. There is also considerable evidence for the negative impacts of agricultural activities and agrochemical use on ecosystem services delivered by natural vegetation, but these impacts have not been assessed for the indigenous crop *Aspalathus linearis* (rooibos). The study was performed on 13 sites in two areas, Nieuwoudtville and Clanwilliam. The sites differed in landscape composition, proximity to natural vegetation and farming practices. I found evidence that rooibos pollination is dependent on flying pollinators and that the natural environment is an important provider of ecosystem services to rooibos farmers. I found higher floral diversity in rooibos fields in close proximity to natural vegetation ($r = 0.16$, $p = 0.015$) and higher floral cover in rooibos fields with higher percentage natural vegetation surrounding the field at different scales, i.e. 1000 and 3000 m radii ($r = 0.14$, $p = 0.038$ and $r = 0.15$, $p = 0.025$, respectively). I also found that bee and wasp diversity and abundance were influenced by the percentage surrounding natural vegetation and the presence of strips (16 to 40% higher in fields in close proximity to natural vegetation). Regarding farming practices, floral cover was on average two orders of magnitude higher in organic as opposed to conventional rooibos fields. Bee and wasp diversity and abundance in organic fields was approximately twice that in conventionally managed sites, possibly due to the absence of agrochemicals as well as increased floral resources. Organic farming practices (*vs.* conventional), result in 10 to 20% increased organic and total soil nitrogen concentrations in rooibos cultivated fields. Organically farmed rooibos fields in close proximity to natural vegetation also resulted in decreased pH levels ($r = 0.92$, $p =$

0.01). Contrary to the case in many organic farms where soil organic matter result in increased soil moisture retention, lower soil volumetric water content were found on organic rooibos farms (29.46%) than conventionally farmed sites (18.84%). Moreover, close proximity to natural vegetation resulted in reduced wind speeds (by up to two orders of magnitude) inside rooibos fields. In conclusion, the natural environment is an important provider of ecosystem services to rooibos farmers.

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Abbreviations

ANOVA – Analysis of variance

AP – Aerial pollinators

BBPG – Biodiversity Best Practice Guidelines

CP – Crawling pollinators

CCD – Colony Collapse Disorder

ESS – Ecosystem services

GCBC – Greater Cederberg Biodiversity Corridor

GLM – General Linear Model

MAP – Mean annual precipitation

MDT – Mean daily temperature

RA – Redundancy analysis

RBI - Rooibos Biodiversity Initiative

RR – Right Rooibos

RTU – Recognizable Taxonomic Unit

VWC – Volumetric water content

WCNCB – Western Cape Nature Conservation Board

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(natural vegetation and rooibos fields, or between conventional and organic fields). Similar trends in wind speed and soil VWC were found at other sampling times (data not shown).

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Chapter 1

GENERAL INTRODUCTION

Background

Aspalathus (Fabaceae, Tribe Crotalarieae) is the second largest genus of flowering plants (after Erica) restricted to South Africa (Goldblatt and Manning, 2002), comprising 279 species (Van Heerden *et al.*, 2003; Cupido, 2007). A few species in this genus currently has economic value, one of which is *Aspalathus linearis* ((Burm. F) Dahlg. Fabaceae), commonly known as "rooibos". The leaves of *A. linearis* are processed and used to make rooibos tea, a commercially important natural health drink that has become popular both locally and abroad. Currently, rooibos tea is both cultivated and harvested from wild populations.

Rooibos is native to the western and south-eastern parts of the Western Cape and to the south-western part of the Northern Cape Province of South Africa (Dahlgren, 1968; 1988). This limited distribution of rooibos mainly falls within the Greater Cederberg Biodiversity Corridor (GCBC), a mega-reserve managed by CapeNature (the provincial conservation body for the Western Cape Province in South Africa) (Fig. 1). Within the GCBC, rooibos production is limited to the Cederberg, Sandveld and Suid-Bokkeveld regions, which lie within the Succulent Karoo and Fynbos biomes.

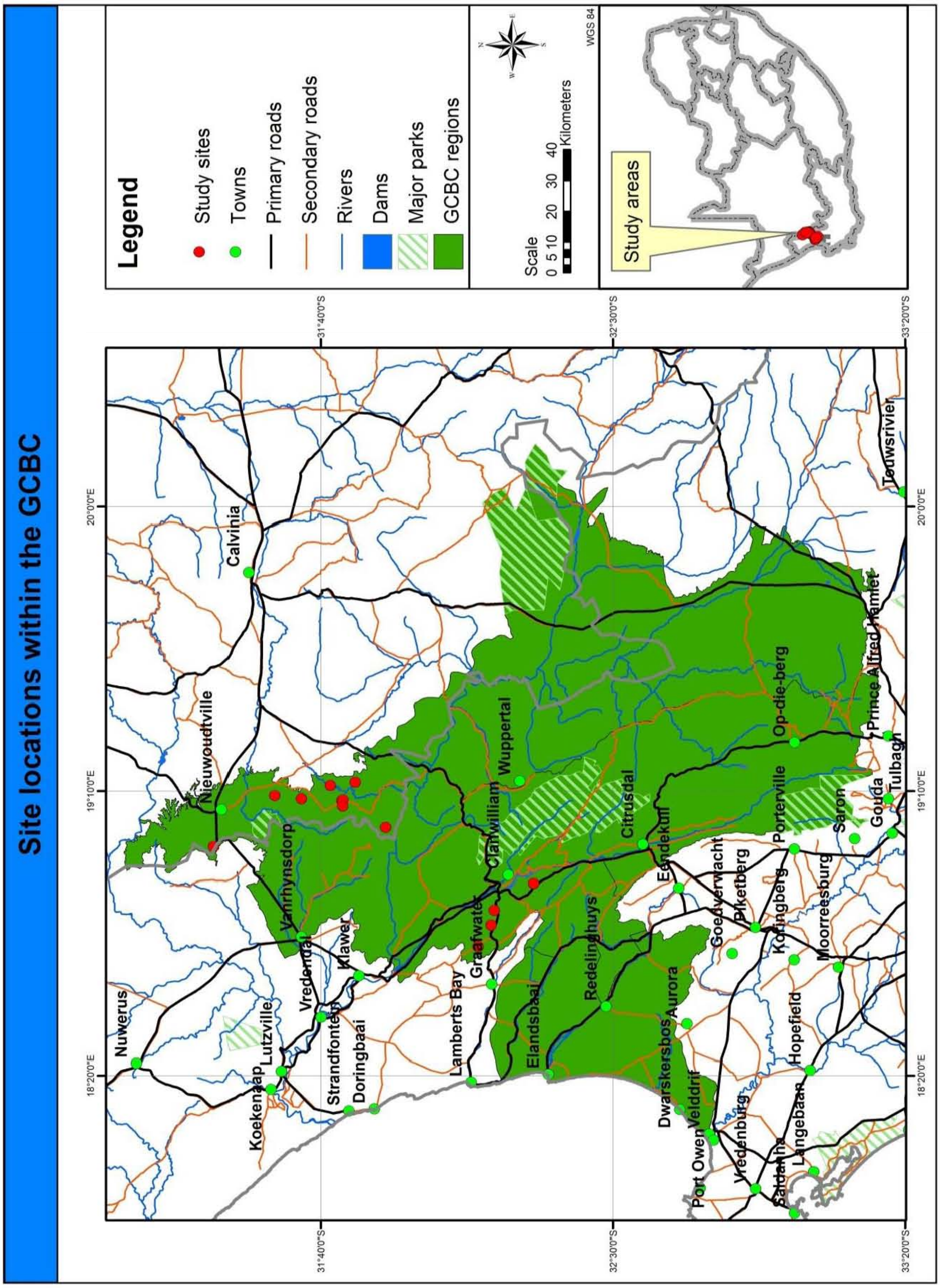

Fig. 1. Map showing the planning domain of the Greater Cederberg Biodiversity Corridor (GCBC, green area) within South Africa. Specific study areas are also shown (red dots). Modified with permission from: Johan Burger, Western CapeNature Conservation Board (WCNCB) trading as CapeNature and the GCBC (Jun 2010).

Aspalathus linearis is adapted to sandy, well-drained acidic soils, where the clay layer is at least one meter below the surface. The quality of the harvested rooibos tea improves with altitude, higher mineral content in the soil and lower temperatures (Cheney and Scholtz, 1963; Low *et al.*, 2004; Hansen, 2006; Nel *et al.*, 2007). As a result, the mountainous areas in the more northerly reaches of the plant's distribution produce the highest quality rooibos, whereas the Sandveld in the south produces the lowest[1]. To ameliorate this, tea from the different production areas is blended to meet demand whilst maintaining a consistent quality (Hansen, 2006; Pretorius, 2008; Malgas *et al.*, 2010).

The rooibos plant has an average lifespan of six years, equating to four crops in an average lifecycle (Bienabe and Troskie, 2007; Pretorius, 2008). Good agricultural practice includes a rest period of two to three years before re-planting, and in a full cycle (growing period plus rotation period) an average lifetime yield of 1500 kg·ha^{-1} (i.e. 375 kg·ha^{-1} per annum), is obtained (Cheney and Scholtz, 1963; Pretorius, 2008). As the sole producer of rooibos worldwide, South Africa has a natural competitive advantage that, with the right regulatory, logistical and marketing support, could make rooibos one of the leading foreign-exchange earners through exports of processed and value-added products (Bienabe and Troskie, 2007; Pretorius, 2008). In recent years the rooibos tea industry has experienced phenomenal growth. According to recent studies an export market growth of 742% between 1993 and 2003 has been reported (Pretorius, 2008).

[1] Most rooibos tea is actually produced in the Sandveld, despite the implications for quality. This is because the northern areas are so mountainous, and the area available for cultivation is therefore quite limited for meeting the growth requirements of rooibos. Complicating matters further, the favourable mountainous areas of the north are often only reached with great difficulty. The areas currently under production are scattered with rocky outcrops making mechanisation almost impossible.

Habitat degradation and the rooibos industry

Whilst the demand for rooibos may be good for the local economy, *A. linearis* grows within two of the world's global plant biodiversity hotspots; the succulent Karoo and the Fynbos (Mucina and Rutherford, 2006), with clear implications for biodiversity both globally and in the region. Within these hotspots, rooibos occurs mainly in three vegetation types, the Cederberg Sandstone Fynbos, Bokkeveld Sandstone Fynbos and Olifants Sandstone Fynbos (Hawkins *et al.*, 2010). Of the 435 vegetation types recognized nationally for South Africa (Mucina and Rutherford, 2006), Cederberg Sandstone Fynbos has the highest number of endemic plant species (195). The Bokkeveld Sandstone Fynbos is also in the top ten most endemic-rich vegetation types, with 101 endemics (Pretorius, 2008). These vegetation types occur mainly in the Sandveld region which rates as the second-most threatened ecosystem in South Africa (Pretorius, 2008). Only about 50% of the Sandveld remains untransformed today.

Many of these endemics are restricted to the deep, well-draining, sandy habitats where rooibos grows. As a result of the massive expansion of the rooibos industry between 1994 and 2007, the rooibos footprint increased four-fold, from 15000 ha in 2005 to 60000 ha in 2008 (Pretorius, 2008) resulting in habitat destruction for a number of species now at risk of extinction. In the '96/'97 Red Data list, 79 species were listed from rooibos production areas, and of these 37 were listed as threatened with extinction (Hilton-Taylor, 1996). In 2009, however, 151 species from the area were red-listed, of which 149 are threatened (Raimondo *et al.*, 2009). Although the inclusion of some of the species on the 2009 red-list may be because of improved detection rates and more information, it still equates to a 300% increase over the past 12 years in the number of species threatened with extinction as a result of cultivation. Within the highest threat categories of "Endangered" and "Critically Endangered", only five species were listed in 1997, yet there are now 57 listed

(CREW database.; Raimondo, 2007; Pretorius, 2008; Raimondo *et al.*, 2009). Against this background of threat to biodiversity, the rooibos footprint is now also expanding to the south-west with major growth taking place in the Redelinghuys (Sandveld) region of the Western Cape.

The production of rooibos has been identified as one of the greatest threats to the natural environment and biodiversity of the GCBC (Low *et al.*, 2004). Other threats to the habitats where rooibos is cultivated include potato farming (Van Wyk, 2002; Botha, 2009), excessive burning, heavy grazing, over-harvesting and periodic drought (Low and Rebelo, 1998). These land uses have led to increased habitat fragmentation and degradation. Continuous habitat has been divided into smaller, frequently isolated areas, often resulting in species loss of both native flora and fauna (Aizen and Feinsinger, 1994). The detrimental effects of fragmentation arise through direct changes in the physical nature and patterns of diversity within the habitat (Lovejoy *et al.*, 1986), as well as changes to ecological processes, edge effects, increased competition and predation and changing dispersal processes (Dunning *et al.*, 1992).

Pollinators, specifically, are at risk in fragmented landscapes due to the increased distances between nesting sites, food resources and available nesting material (Donaldson, 2002; Kim *et al.*, 2006). For example, solitary bees (a potential pollinator of rooibos, see Chapter 2) need a number of different resources located within foraging range of their nest in order for them to reproduce successfully (Gathmann *et al.*, 1994; Tscharntke *et al.*, 2005). The foraging distance is thought to be between 150 and 600 m for most species of bees (Gathmann and Tscharntke, 2002). Due to the rapidly expanding rooibos market, not only is there increasing fragmentation of natural habitat, but rooibos field sizes are also expanding, leading to increased foraging distances for insects. These factors pose a significant threat to insect pollinators in the region. The loss of pollinators would directly impact the rooibos industry, since plants are propagated by seed collected from cultivated lands (Cheney and Scholtz, 1963), and other methods of propagation (e.g. growing plants from cuttings) have yet to prove successful (Dawie de Villiers, Cape Natural Tea Products, pers comm. 2008).

The "Right Rooibos Initiative"

In response to the clearly conflicting needs of biodiversity conservation and economic pressures for a viable rooibos industry, the South African Rooibos Council, in association with CapeNature, started the Rooibos Biodiversity Initiative (RBI) in 2007 (called Right Rooibos (RR) since 2010) to encourage best practices in the area. Recently completed guidelines for best practices include criteria on social, economic and environmental principles (e.g. on land stewardship, alien invasive plant eradication, judicious chemical use, restoration of surrounding areas, compliance with the law regarding dam building, and ploughing). Understanding of, and outcomes from, application of the above principles including benefits of ecosystem services (services the environment delivers to humans – see below for a full definition) in and around farms, may incentivize farmers to comply with RR guidelines. In addition, local and international markets have shown interest in RR, thus increasing the demand for sustainably grown rooibos. The rooibos industry is currently considering several certification systems, some of which are associated with a price premium, which may further bring about behaviour change. At present farmers in the Sandveld make use of vegetation strips (*ca.* 5 to 10 m) to reduce wind erosion. These vegetation strips generally consist on linear natural vegetation corridors left undisturbed inside the rooibos fields. However, it is possible that these strips also provide other ecosystem services such as habitat for pollinating insects.

The importance of ecosystem services for the rooibos industry

Ecosystem services (ESS) are the conditions and processes through which natural ecosystems and the species that constitute them, sustain and fulfill human life, as well as encompass all the benefits we derive, directly or indirectly, from the effective functioning of ecosystems (Daily, 1997; Costanza *et al.*, 1998). ESS include ecosystem goods, such as seafood, game animals, fodder, fuelwood, timber, pharmaceutical products, wild flowers and wild rooibos tea, as well as ecosystem functions, such as the purification of air and water, detoxification and decomposition of wastes, climate regulation, soil nutrient cycling, and production and maintenance of biodiversity (Daily *et al.*, 1997). ESS also includes many intangible aesthetic and cultural benefits (Daily, 1997).

It is likely that farming may benefit from ESS operating at different scales as well as from on-site (e.g. in the form of nutrient cycling, temperature moderation, pollination and pest control) and offsite (e.g. flood attenuation and water provision) sources. Of particular interest to rooibos farming are pollination, nutrient cycling and erosion prevention, all of which are provided by, in one form or another, areas under natural vegetation, potentially including vegetation strips. Since rooibos is currently only cultivated from seed, pollination may be one of the most important ESS to the rooibos industry. This taken into account, the dependence of rooibos on insect pollinators remains unconfirmed although it is thought that rooibos is self-incompatible and dependent on solitary wasps and bees for pollination (Gess and Gess, 1994; Gess, 2000).

Research objectives

The main objectives of this dissertation were to test whether areas covered by natural vegetation (surrounding the farm or as vegetation strips) provide ESS (in the form of pollination, nutrient cycling, windbreaks and temperature moderation) to rooibos production, and to test the influence of agrochemicals on these ESS by comparing organic and conventional farming methods of rooibos. The overall objective was to inform the RR best practice guidelines regarding the use of vegetation strips and the area of surrounding natural vegetation required to provide ESS.

I explored the following hypotheses:

1) Greater percentage natural vegetation cover (as natural vegetation strips or surrounding vegetation) is associated with greater abundance and diversity of insects (specifically Order Hymenoptera, which includes pollen wasps and solitary bees), as well as rooibos seed set on rooibos farms due to increased habitat and floral resources for these insects (Chapter 2);

2) Floral resources, the abundance and diversity of pollinating insects and rooibos seed set are adversely affected by agrochemical use (Chapter 2);

3) Natural vegetation (as natural vegetation strips or surrounding vegetation) regulate wind, farm soil moisture and air temperature, and supports nutrient cycling, measured as soil nutrient concentrations (Chapter 3); and

4) Organic (as opposed to conventional) rooibos production results in increased soil moisture and improved nutrient cycling (measured as soil nutrient concentrations) (Chapter 3).

Study areas

This study was conducted from 2008 to 2010 near two towns, Nieuwoudtville and Clanwilliam, which occur in the Northern and Western Cape of South Africa respectively (Fig. 2). The two study areas are situated about 135 km from each other. Sites within these areas differed with regard to landscape composition (percentage natural vegetation surrounding rooibos fields[2]), field size (diameter) and farming practices (organic and conventional) (Table 1). The extent to which environmental factors contributed to varying results in the two areas was assessed and controlled for (see Chapter 2 – Preliminary analysis of regions).

Nieuwoudtville

The study sites chosen for this investigation were on the Bokkeveld Plateau near Nieuwoudtville (31º 22.765' S, 19º 6.479' E), a farming area in which the primary agricultural activities are sheep farming, wheat and rooibos production. The Bokkeveld Plateau (800 m above sea level) is situated 350 km north of Cape Town embracing an area some 100 by 75 km, stretching from the Bokkeveld Mountains and Van Rhyn's Pass in the west through Nieuwoudtville to the town of Calvinia in the east, and to the Botterkloof in the south (Manning and Goldblatt, 1997). The annual rainfall varies from over 500 mm at the edge of the escarpment in the west to 300 mm near Calvinia in the east. The Bokkeveld Plateau has a particularly high plant diversity (*ca.* 1350 species) and endemism (6.5%) (Donaldson, 1999).

As previously mentioned, the mountainous nature of the area means that field dynamics (e.g. field size and farming practices), are limited in this area. Nine sites on six small-scale farms, with rooibos field diameters ranging from 200 to 400 m, were selected (Fig. 2). The dominant agricultural activity is rooibos production, although some farmers have livestock grazing the surrounding vegetation. Four of these sites are conventionally farmed while the remaining five are farmed organically.

[2] The percentage natural vegetation surrounding the fields is the area or size of the surrounding landscape that consist of natural vegetation and not of agricultural fields.

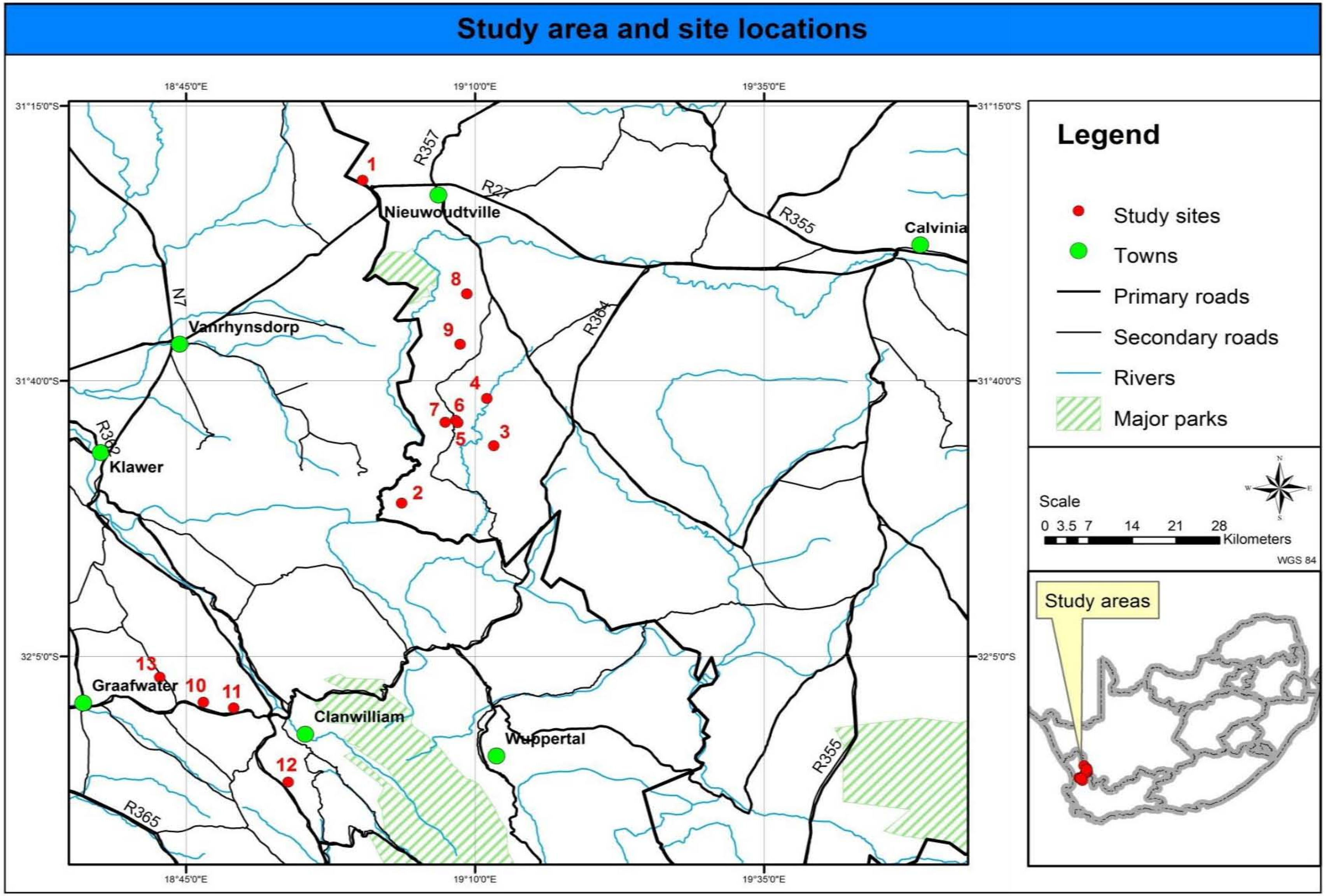

Fig. 2. The locations of the nine study sites. Site numbers refer to locations shown in Table 1.

Table 1. Site references, agricultural practices in the study years and landscape characteristics for 13 study sites (situated on 11 farms).

Site number	Farm name	General location	Reference point		Altitude (m)	Strips present	Farming type
			Natural vegetation	Middle of rooibos field			
1	Cloudkraal	Suid Bokkeveld, Nieuwoudtville	S31°21.793' E019°00.235'	S31°21.740' E019°00.283'	841	No	Conventional
2	Sonderwaterkraal	Suid Bokkeveld, Nieuwoudtville	S31°51.075' E019°03.621'	S31°51.088' E019°03.659'	424	Yes	Organic
3	Dobbelaarskop	Suid Bokkeveld, Nieuwoudtville	S31°45.873' E019°11.564'	S31°45.887' E019°11.615'	680	Yes	Organic
4	Lokenburg	Suid Bokkeveld, Nieuwoudtville	S31°41.588' E019°11.001'	S31°41.599' E019°11.027'	643	No	Organic
5	Blomfontein (1)	Suid Bokkeveld, Nieuwoudtville	S31°43.489' E019°08.414'	S31°43.585' E019°08.328'	776	No	Conventional
6	Blomfontein (2)	Suid Bokkeveld, Nieuwoudtville	S31°43.790' E019°08.516'	S31°43.785' E019°08.504'	775	No	Organic
7	Blomfontein (3)	Suid Bokkeveld, Nieuwoudtville	S31°43.722' E019°07.406'	S31°43.750' E019°07.426'	739	No	Organic
8	Papkuilsfontein	Suid Bokkeveld, Nieuwoudtville	S31°32.208' E019°09.328'	S31°32.114' E019°09.286'	712	Yes	Conventional
9	Onder Melkkraal	Suid Bokkeveld, Nieuwoudtville	S31°36.680' E019°08.712'	S31°36.678' E019°08.703'	728	Yes	Organic
10	Ysterfontein (1)	Southern Cederberg, Clanwilliam	S32°08.921' E018°46.851'	S32°09.147' E018°46.500'	306	No	Conventional
11	Ysterfontein (2)	Southern Cederberg, Clanwilliam	S32°09.603' E018°48.067'	S32°09.890' E018°48.295'	392	Yes	Conventional
12	Nooitgedacht	Southern Cederberg, Clanwilliam	S32°16.217' E018°53.866'	S32°16.418' E018°53.823'	332	No	Conventional
13	Groenkol	Southern Cederberg, Clanwilliam	S32°06.947' E018°42.624'	S32°06.888' E018°42.719'	435	No	Conventional

Clanwilliam

The Clanwilliam (32º 10.804’ S, 18º 53.260 E) study sites occur in the southern region of the Cederberg, a farming area in which the main agricultural practices are sheep farming and fruit, vegetable and rooibos production. This area (100 m above sea level) is situated 220 km north of Cape Town. Like the Nieuwoudtville area, the area has a Mediterranean climate with hot, dry summers and cold, wet winters. Most of the rain falls between May and September and the rainy conditions usually last several days. Rainfall is strongly affected by the orographic nature of the landscape, consequently annual rainfall in some mountain ravines is in excess of 1270 mm as opposed to a meager 250 mm in the eastern valleys near Wuppertal (Van Rooyen and Steyn, 1999). The mean annual precipitation for 2008 in the town of Clanwilliam was 420 mm (South African Weather Bureau). This region is roughly in the middle of the Mountain Fynbos biome occurring predominantly on sandstones, which typically yield well-leached, infertile soils.

Four sites on three large-scale farms around the Clanwilliam area were selected for this investigation (Fig. 2). All four of these sites are conventionally farmed with field diameters ranging between 300 and 1000 m. The main activity on these farms is rooibos production, although most farmers also crop-rotate or interplant with oats (*Avena sativa* L.).

Specific study sites

I selected a total of 13 sites within the above mentioned study areas, nine from Nieuwoudtville and four from Clanwilliam, of which eight were conventionally farmed and five were organically farmed (Table 1, Fig. 2). Sites were categorized as organic or conventional based on the absence or use of agrochemicals (i.e. pesticides, insecticides and herbicides) respectively. These sites differ with regard to rooibos field size (proximity to natural vegetation[3]) as well as the percentage natural vegetation surrounding the field (Table 2). The proximity of the natural vegetation to the middle of the rooibos field is used as an estimator of how far insect need to fly from the natural vegetation (nesting sites etc.) in order to reach the floral resources in the middle of the field. In rooibos fields where no strips are present, this distance is greatly increased as insects also use the strips for nesting sites. In order to determine the distance that the insects need to fly, I took the minimum diameter of the field and divided it by to get the minimum filed radius. This distance is thus the minimum distance that insects need to fly from the closest natural vegetation to the middle of the rooibos field. The percentage natural vegetation is used as an estimator for the area surrounding the rooibos fields and as this area or percentage increase, the space available for insects for nesting, additional floral and water resources, increases. It is thus presumed that as the percentage natural vegetation increases, the amount of insects surrounding the field also increase.

Triplicate transects (25 x 1 m, 20 m apart) were laid out in the nearest natural vegetation (25 m from edge) surrounding the rooibos field and one in the middle of the rooibos field for each site. The central transects in the natural vegetation and rooibos field were georeferenced. These transects were used to determine floral resource cover and abundance, insect abundance as well as to take soil samples, soil moisture readings, wind speed measurements and air temperature readings. If more than one site was used on a particular farm, sites were separated by at least 5 km. Study sites were visited five times in total, i.e. twice in spring (Sept 2008 and 2009) and once in summer (Dec 2008), autumn (Mar 2009) and winter (Jul 2009).

[3] Proximity to natural vegetation $= \frac{\text{Minimum field diameter}}{2}$

References

AIZEN, M.A. & FEINSINGER, P. 1994. Habitat fragmentation, native insect pollinators, and feral honey bees in Argentine 'Chaco Serrano'. *Ecological Applications*, 4, 378-392.

BIENABE, E. & TROSKIE, D. 2007. SINER-GI: Case study report (Rooibos).

BOTHA, L. 2009. Rooibostee: Boere gaan groen. *Landbou Weekblad.*

CHENEY, R.H. & SCHOLTZ, E. 1963. Rooibos tea, a South African contribution to world beverages. *Economic Botany*, 17, 186-194.

COSTANZA, R., D'ARGE, R., DE GROOT, R.S., FARBER, S., GRASSO, M., HANNON, B., K., L., NAEEMS., O'NEILL, R.V., PARUELO, J., RASKIN, R.G., SUTTON, P. & VAN DEN BELT, M. 1998. The value of ecosystem services: Putting the issues in perspective. *Ecological Economics*, 25, 67-72.

CREW DATABASE. Custodians of Rare and Endangered Wildflowers. South Africa.

CUPIDO, C.N. 2007. Notes on African plants: Fabaceae. *Aspalathus theresae*, a new species from Western Cape, South Africa. *Bothalia*, 37, 34.

DAHLGREN, R. 1968. Revision of the genus Aspalathus II: The species with ericoid and pinoid leaves. 7 subgenus Nortieria. With remarks on rooibos cultivation. *Botaniska Notiser*, 121, 165-208.

DAHLGREN, R. 1988. Revision of the genus Aspalathus. *Flora of Southern Africa*, 16, 1-430.

DAILY, G.C. 1997. Introduction: What are ecosystem services? *In:* DAILY, G.C. (ed.) *Nature's Services: Societal dependence on natural ecosystems.* Washington, D.C: Island Press.

DAILY, G.C., ALEXANDER, S., EHRLICH, P.R., GOULDER, L., LUBCHENCO, J., MATSON, P.A., MOONEY, H.A., POSTEL, S., SCHNEIDER, S.H., TILMAN, D. & WOODWELL, G.M. 1997. Ecosystem services: Benefits supplied to human societies by natural ecosystems. *Ecology,* 2, 1-18.

DONALDSON, J.S. 1999. Conservation of globally significant biodiversity in agricultural landscapes in South Africa through conservation farming. *Global Environmental Facility Targeted Research Proposal.* Cape Town: National Botanical Institute.

DONALDSON, J.S. 2002. Pollination in agricultural landscapes, a South African perspective. *In:* KEVAN, P. & IMPERATRIZ FONSECA, V.L. (eds.) *Pollinating Bees - The Conservation Link Between Agriculture and Nature.* Brasília: Ministry of Environment.

DUNNING, J.B., DANIELSON, B.J. & PULLIAM, H.R. 1992. Ecological processes that effect populations in complex landscapes. *Oikos,* 65, 169-175.

GATHMANN, A., GREILER, H.J. & TSCHARNTKE, T. 1994. Trap-nesting bees and wasps colonizing set-aside fields: Succession and body size, management by cutting and sowing. *Oecologia,* 98, 8-14.

GATHMANN, A. & TSCHARNTKE, T. 2002. Foraging ranges of solitary bees. *Journal of Animal Ecology,* 71, 757-764.

GESS, S.K. 2000. Rooibos, refreshment for humans, bees and wasps – The flower visitors and pollinators of Aspalathus. *Veld & Flora.*

GESS, S.K. & GESS, F.W. 1994. Potential pollinators of the Cape Group of Crotalarieae (sensu Polhill) (Fabales: Papilionaceae), with implications for seed production in cultivated rooibos tea. *African Entomology,* 2, 97-106.

GOLDBLATT, P. & MANNING, J.C. 2002. Plant diversity of the Cape region of Southern Africa. *Annals of the Missouri Botanical Garden,* 89, 281-302.

HANSEN, T. 2006. Sustainable Rooibos Initiative: A sustainable production strategy for the South African rooibos tea industry. *Commissioned by the CapeNature Greater Cederberg Biodiversity Corridor (GCBC) and the South African Rooibos Council (SARC).* Cape Town, South Africa.

HAWKINS, H.-J., MALGAS, R.R. & BIENABE, E. 2010. Ecotypes of wild rooibos (*Aspalathus linearis* (Burm. F) Dahlg., Fabaceae) are ecologically distinct. *South African Journal of Botany,* in press.

HILTON-TAYLOR, C. 1996. *Red Data list of southern African plants.* Pretoria: National Botanical Institute.

KIM, J., WILLIAMS, N.M. & KREMEN, C. 2006. Effects of cultivation and proximity to natural habitat on ground-nesting native bees in California sunflower fields. *Journal of the Kansas Entomological Society,* 79.

LOVEJOY, T.E., BIERREGAARD, R.O., RYLANDS, A.B., MALCOLM, C.E., QUINTELA, C.E., HARPER, L.H., BROWN, K.S., POWELL, A.H., POWELL, G.V.N., SCHUBART, H.O.R. & HAYS, M.B. 1986. Edge and other effects of isolation on Amazon forest fragments. *In:* SOULE, M.E. (ed.) *Conservation biology: The science of scarcity and diversity.* Massachusetts, USA: Sinauer.

LOW, A.B., MUSTART, P. & VAN DER MERWE, H. 2004. Greater Cederberg Biodiversity Corridor: Provision of biodiversity profiles for management. *Greater Cederberg Biodiversity Corridor – Profiles.*

LOW, A.B. & REBELO, A.G. 1998. Vegetation of South Africa, Lesotho and Swaziland. South Africa: Department of Environmental Affairs and Tourism.

MALGAS, R.R., POTTS, A.J., OETTLÉ, N.M., KOELLE, B., TODD, S.W., VERBOOM, G.A. & HOFFMAN, M.T. 2010. Distribution, quantitative morphological variation and preliminary molecular analysis of different growth forms of wild rooibos (*Aspalathus linearis*) in the northern Cederberg and on the Bokkeveld Plateau. *South African Journal of Botany,* 76, 72-81.

MANNING, J. & GOLDBLATT, P. 1997. *Nieuwoudtville, Bokkeveld Plateau and Hantam.* Cape Town, South Africa: Botanical Society of South Africa.

MUCINA, L. & RUTHERFORD, M.C. 2006. *The vegetation of South Africa, Lesotho and Swaziland.* Pretoria: South African National Biodiversity Institute.

NEL, E., BINNS, T. & BEK, D. 2007. Alternative foods and community-based development: Rooibos tea production in South Africa's West Coast Mountains. *Applied Geography,* 27, 112-129.

PRETORIUS, G. 2008. Rooibos Biodiversity Initiative (RBI): Biodiversity best practice guidelines for the sustainable production of rooibos. *The South Africa Rooibos Council (SARC) in partnership with the CapeNature Greater Cederberg Biodiversity Corridor (GCBC) Project Management Unit.* Malmesbury, South Africa: Natura Libra Environmental Consultants.

RAIMONDO, D. 2007. Custodians of Rare and Endangered Wildflowers (CREW) in summer-rainfall South Africa. *Plantlife,* 36, 27-37.

RAIMONDO, D.C., VAN STADEN, L., FODEN, W., VICTOR, J.E., HELME, N.A., TURNER, R.C., KAMUNDI, D.A. & MANYAMA, P.A. (eds.) 2009. *Red list of South African plants 2009.* Pretoria: South African National Biodiversity Institute.

TSCHARNTKE, T., RAND, T.A. & BIANCH, F.J.J.A. 2005. The landscape context of trophic interactions: Insect spillover across the crop-noncrop interface. *Annales Zoologici Fennici,* 42, 421-432.

VAN HEERDEN, F.R., VAN WYK, B.-E., VILJOEN, A.M. & STEENKAMP, P.A. 2003. Phenolic variation in wild populations of *Aspalathus linearis* (rooibos tea). *Biochemical Systematics and Ecology,* 31, 885-895.

VAN ROOYEN, G. & STEYN, H. 1999. *Cederberg, Clanwilliam and Biedouw valley.* Cape Town: Botanical Society of South Africa.

VAN WYK, B.-E. 2002. A review of ethnobotanical research in southern Africa. *South African Journal of Botany*, 68, 1-13.

Chapter 2

FACTORS AFFECTING ROOIBOS POLLINATORS: PROXIMITY, PERCENTAGE NATURAL VEGETATION OR FARMING METHODS?

Abstract

Farming practices and landscape composition may affect various ecosystem services. To date, whether rooibos is insect pollinated remains unconfirmed, and there have been no studies on the effects of landscape composition and farming practices on insect pollinators of *Aspalathus linearis* (rooibos). Here, I used exclusion experiments to ascertain whether rooibos is insect pollinated or not. I investigated how the diversity and abundance of insects and floral resources varied with farming practices, landscape composition and proximity to natural vegetation in the Nieuwoudtville and Clanwilliam rooibos production areas of South Africa. Pollination efficiencies were 10 times higher in open bags *vs.* closed bags suggesting that rooibos relies to a great extent on flying insect pollinators. I found higher floral diversity in rooibos fields in close proximity to natural vegetation and higher floral cover in rooibos fields with higher percentage natural vegetation surrounding the field in 1000 and 3000m radii. I also found that bee and wasp diversity and abundance were influenced by the percentage surrounding natural vegetation and the presence of strips. Rooibos fields in close proximity to natural vegetation (< 500 m), had higher bee/wasp diversity and abundance (16 to 40% higher in fields in close proximity), possibly because of lower foraging distances for insects, with the expected effect of increased

percentage rooibos seed set. Regarding farming practices, floral cover was on average two orders of magnitude higher in organic as opposed to conventional rooibos fields. Bee and wasp diversity and abundance in organic fields were approximately twice that in conventionally managed sites, possibly due to the absence of agrochemicals as well as increased floral resources. These results suggest that as much surrounding vegetation as possible should be left and field size should be less than 500 m (edge to middle), to maximise pollination and seed set of rooibos plants. Organic farming practices are also far better than conventional practices, for insects.

Introduction

Pollination is one of the most important supporting (also see Chapter 1) ecosystem services (ESS), enabling plant reproduction and food production for humans and animals. Insect pollination is currently estimated to be required for approximately 35% of the global food production volume (Hawkins *et al.*, 2010). Flower-visiting bees (Hymenoptera: Apoidea) are recognized as the most important pollinator taxon (Steffan-Dewenter and Tscharntke, 1999; Goldblatt and Manning, 2000) and are also the primary pollinators for most ecological regions in the world (Greenleaf *et al.*, 2007). Animal pollinators are thought to account for 75% of all major crop species' and around 80% of all flowering plant species' pollination. Of the approximately 100 principal animal-pollinated crop species, at least 15 species are pollinated by domestic bees and roughly 80 of these crop species are pollinated by wild bee species and other wild life (Kremen, 2004).

Although it is known that for diversity among plants, including "food diversity", pollinator diversity is essential, very little research has been conducted to determine the extent to which bees contribute to crop pollination under various circumstances (Kremen and

Ricketts, 2000; Kremen *et al.*, 2002; Kremen, 2004). Which species contribute, the economic value of this contribution and their susceptibility to environmental changes such as habitat loss and degradation is also yet to be determined (Kremen and Ricketts, 2000; Kremen *et al.*, 2002; Kremen, 2004). The phenomenon of declining pollinator populations and the various consequences thereof has been well established (Nabhan and Buchmann, 1997; Allen-Wardell *et al.*, 1998; Donaldson, 2002).

In South Africa, most crop pollination research to date has concentrated on managed honeybees (*Apis mellifera*) and there are two major issues for honeybees in this country. First is the "Cape honeybee problem" in which the hives of African honeybees (*A. mellifera scutellata*) are destroyed after Cape honeybee (*A. mellifera capensis*) workers gain access to the host hive (Donaldson, 2002). Second, the *Varroa* mite (*Varroa destructor;* an ectoparasite) has spread to seven of the nine provinces after first being recorded in South Africa in 1997 (Donaldson, 2002; Volk and Forshaw, 2004). Originating in Asia, it has caused widespread colony loss worldwide. In Europe and the USA, where the mite is well established, wild honeybee colonies have all but disappeared and researchers believed it to be primarily as a result of the varroa mortality (Donaldson, 2002; Davison *et al.*, 2003; Allsopp, 2004). The above problems may be presumed to be the major causes of honeybee decline in South Africa, but after the devastating effects of the collapse of bee colonies in 22 states in America, the situation might have to be reassessed. The sudden decline of honey bees has been termed "Colony collapse disorder" (CCD), and has been reported to have claimed 80 to 100% of the colonies of some beekeepers in America during 2007 (Raiesi and Ghollarata, 2006). The CCD is now thought to be a multi-factorial syndrome where bees might be suffering from immune-suppression due to a number of causes, including in-hive chemicals, agricultural insecticides, genetically modified crops, changed cultural practices, cool brood and diseases and parasites (of which *V. destructor* is one) (Scholtz and Holm, 1985; Raiesi and Ghollarata, 2006).

Although there is no official confirmation of CCD in South Africa, habitat loss and habitat fragmentation pose another threat to already declining pollinator populations. Various studies have demonstrated the negative impact of extensive farming systems and farming practices on pollinator fauna (Kremen *et al.*, 2002; Luig *et al.*, 2005; Carvalheiro *et al.*, 2010). Included in these activities is stock farming where grazing patterns and trampling affect the availability of floral resources and suitable nesting sites (Gess and Gess, 1993; Donaldson, 1999; 2002). By investigating the optimal habitat structure and proximity to resources, pollinator populations may be better able to resist the various natural enemies they already face.

Natural or semi-natural vegetation as well as vegetation corridors (strips) provide floral (food) resources and nesting sites for pollinators, the proximity of which influences pollinator diversity and abundance within crop fields (Aizen and Feinsinger, 1994; Steffan-Dewenter and Tscharntke, 1999; Cunningham, 2000; Kruess and Tscharntke, 2000; Stefan-Dewenter, 2002; Kremen *et al.*, 2004; Kim *et al.*, 2006). This pollinator diversity and abundance seems to correlate with the delivery of pollination services to crops, with the proximity of natural vegetation also shown to influence crop pollination, in turn affecting quality and quantity of crop yields and seed set (Ghazoul, 2005; Diekötter *et al.*, 2006; Greenleaf *et al.*, 2007). Crops for which this effect has been demonstrated include coffee (Klein *et al.*, 2003; Ricketts, 2004), cashew (Heard *et al.*, 1990), macadamia (Heard and Exley, 1994) and mango (Anderson *et al.*, 1982; Carvalheiro *et al.*, 2010).

Increasing habitat fragmentation and decreasing amounts of natural vegetation surrounding cultivated fields could hamper pollinator movement between foraging and nesting sites

(Saunders *et al.*, 1991; Ricketts, 2001) as well as limit floral resources, ultimately changing ecosystem function (Steffan-Dewenter *et al.*, 2002). Solitary bees have small (i.e. 100 to 250 m) foraging ranges (Gathmann and Tscharntke, 2002), so species diversity and abundance of solitary wild bees are expected to be closely related to the percentage of semi-natural habitats at small scales (Steffan-Dewenter *et al.*, 2002) and proximity gradients to natural vegetation around cultivated fields (Gathmann and Tscharntke, 2002; Steffan-Dewenter *et al.*, 2002).

Aspalathus linearis (rooibos) is thought to be self-incompatible (Gess and Gess, 1994; Mayer, 2005), with a pea-shaped flower which offers rich nectar rewards, although these rewards are not available to all insects (Gess, 2000). The structure of the flower is such that only potential pollinators are able to reach the nectar (Gess, 2000). The potential pollinators trigger the opening of the keel and pollen can be deposited on the insect (Mayer, 2005). Although a wide variety of insects can be seen on the flowers, especially honeybees (*A. mellifera*), it has been thought that honeybees do not pollinate them but only take nectar from the side of the flower without tripping them, and thus do not pollinate the flowers (Gess, 2000). The rooibos industry is dependent on seed set for propagation of the crop as other vegetative propagation methods, i.e. cuttings, have yet to prove commercially viable. In spite of this dependence of the industry on seed, very little is known about the identity of pollinators, and there is scant data regarding insect visitors. The most comprehensive study on the pollinators of rooibos to date is that of Gess and Gess (1994) conducted in the Western and Eastern Cape. In that study they identified solitary bees of the Megachilinae (Megachilidae) and Anthophorinae (Anthophoridae) as well as some of the pollen wasps (Vespidae: Masarinae) as the most likely pollinators of rooibos (hereafter bees and wasps), with species from the genera *Chalicodoma, Spinanthidium* and *Xylocopa* being identified to date (Gess and Gess, 1994; Gess, 2000).

Many of these bee and wasp species are restricted to foraging on *Aspalathus* spp. (Mayer, 2005; Westphal *et al.*, 2008), and a number of *Aspalathus* spp. (e.g. *A. pulicifolia* and *A. spinescens)* occur naturally in the undisturbed vegetation of the areas in which rooibos is cultivated. Some rooibos pollinators also forage on species in the *Lebeckia*, *Wiborgia* and *Rafnia* genera of the Papilionaceae (Mayer, 2005), which may provide floral resources for these insects during the periods when rooibos is non-flowering. They are also mostly multi-habitat users that depend on nesting sites within natural vegetation and food resources (*Aspalathus* spp.) in cultivated land, and these two areas are often spatially separated. Pollinator populations cannot be maintained by short-flowering crops alone, but also need a continuous supply of nectar and pollen in the surrounding agricultural landscapes (Holzschuh *et al.*, 2007). Although an abundance of annually flowering plant species[4] can be found within rooibos fields (Fig. 3), these species are mainly from the Asteraceae family, with little or no pollinators overlapping with those (potentially) identified for rooibos. The occurrence of these annuals is largely because the disturbed rooibos fields provide an open niche for these plants (no perennial competitors and no weeding).

As mentioned earlier, species diversity and abundance of wild bees are expected to be closely related to the percentage of semi-natural habitats at small scales (Steffan-Dewenter *et al.*, 2002) and the proximity of cultivated fields to natural vegetation (Gathmann and Tscharntke, 2002; Steffan-Dewenter *et al.*, 2002). Presently, to reduce wind and water erosion, rooibos farmers use windbreaks usually 5 to 10 m wide (also called strips)

[4] These annual species flower mostly from August to October, overlapping the flowering time of rooibos.

between cultivated blocks, which comprise natural or planted vegetation. It is known that these strips act as effective windbreaks, as wind speed was negatively correlated with vegetation cover (see Chapter 3), but it is not known whether they also provide other ESS including providing habitat and forage for insects. The question therefore arises as to whether these strips act to decrease the proximity to natural vegetation and thus the foraging distance in large rooibos fields.

Fig. 3. Annual flower display in Nieuwoudtville, Northern Cape (left) and annuals flowering inside a rooibos field (right) in Sept 2009 (rainy season).

The purpose of this study was to determine how landscape composition and vegetation strips contribute to the diversity of insects in rooibos fields, and how this might influence rooibos pollination and seed-set. I investigated the effect of landscape composition at three different spatial scales as well as proximity to natural vegetation on bee/wasp abundance and pollination (seed set). I hypothesized that:

1) Rooibos seed set is dependent on insect pollinators (probably solitary bees and pollen wasps);

2) Greater percentage natural vegetation cover (as natural vegetation strips or surrounding vegetation) is associated with greater abundance and diversity of insects (specifically Order Hymenoptera, which includes pollen wasps and solitary bees), as well as rooibos seed set on rooibos farms due to increased habitat and floral resources for these insects; and

3) Floral resources, the abundance and diversity of pollinating insects and rooibos seed set are adversely affected by agrochemical use.

The following general objectives were investigated in order to investigate the main hypotheses:

- Natural vegetation (as opposed to rooibos fields), proximity to natural vegetation and increased percentage natural vegetation surrounding rooibos fields results in increased floral cover and diversity;

- Abundance and diversity of bees and wasps increases with increasing percentage of natural habitats/vegetation within landscapes at three different scales (i.e. radii of 500, 1000 and 3000 m);

- Abundance and diversity of bees and wasps within rooibos fields increases with increasing proximity to natural habitat, the presence of (planted/natural vegetation) strips and with increasing floral cover;

- Organic (as opposed to conventional) rooibos production results in increased floral cover (perennial, annual and overall) and higher abundance and diversity of bees and wasps; and

- Rooibos seed set increases with proximity to natural vegetation.

Methods and materials

Preliminary analysis of study regions

Since study sites spanned two regions differing somewhat in altitude and rainfall, it was necessary to determine the extent to which environmental variables confounded the comparison of sites when determining the effects of farming practice and proximity to natural vegetation.

Environmental variables such as rainfall, temperature, elevation (altitude), slope and aspects were obtained when visiting the sites and assessed as factors (besides test factors) contributing to variability in floral diversity (also known as richness) and insect abundance and diversity by using a Redundancy Analysis (RA, distance biplot) as well as a General Linear Model (GLM). Mean annual precipitation (MAP) and mean daily temperature (MDT) data over 6 to 11 years (depending on availability) were obtained from the South African Weather Service (2009) and South African Atlas of Agrohydrology and Climatology (Schulze et al., 2000).

Site characterization and assessment

Farms were chosen to capture variation in proximity to natural vegetation (including vegetation strips), as well as the type of farming practice (conventional or organic) used to produce rooibos (Table 1). Sites were categorized as organic or conventional based on the absence or use of agrochemicals (i.e. pesticides, insecticides and herbicides) respectively. At each site (n = 13), I surveyed rooibos fields and adjacent natural vegetation as well as vegetation strips, where they existed, for floral cover and at selected sites (n = 4) for flower-visiting insects. I established a reference point in each location (i.e. rooibos field, natural vegetation or strip) and laid out three transects, the central transect on the reference point (see Chapter 1 – Study areas), such that there were six transects at each site without strips and nine transects at each site with strips.

Rooibos pollinators, pollination efficiency and contribution of insect pollination

In mid-Sept 2009, two branches of 30 rooibos plants were bagged[5] (40 x 40 cm draw-string Voille bag with mesh size 2 x 2 mm, Fig. 4) on each of the four Clanwilliam sites (sites 10 to 13), i.e. a total of 120 plants were bagged. Clanwilliam sites were chosen for their relative easy accessibility and proximity to one another. The bagged branches comprising 50 to 200 flower buds each were also smeared with Vaseline around the base to exclude ants. Both treatments and controls were set up on the same plant using the same method but the bags for the control treatment were cut open at the top. This resulted in the same rooibos bush having a treatment branch that excluded aerial pollinators (AP) and crawling pollinators (CP) but still allowed self-pollination (SP), as well as a control branch which excluded CP but allowed AP and SP. A total number of 240 bags were thus set out. During the fruiting season (Jan 2010) the bagged branches were collected and the number of flowers, pods and seeds produced per branch collected inside the bags were counted.

[5] Mesh bags did not appear to affect flower production (trial, Sept 2008, data not shown).

Pollination efficiency was determined as: $\frac{number\ of\ pods}{number\ of\ flower} \times 100$. The contribution of insect pollination was determined as: $pollination\ efficiency\ (open\ bags) - \ pollination\ efficiency\ (closed\ bags)$.

Fig. 4. Closed and opened (red arrow) bagged branches on the same rooibos plant (left) and yellow delta traps elevated to rooibos height (insert showing insect on liner inside the trap) (right).

Quantifying landscape context

I calculated percentage natural vegetation within circles of 500, 1000 and 3000 m radii around the field center for each site. These radii were chosen because solitary wild bees, which were identified as potential pollinators, have been shown to be influenced by the landscape on these small spatial scales (Gess and Gess, 1994; Gathmann and Tscharntke, 2002; Steffan-Dewenter *et al.*, 2002). Percentage natural vegetation and proximity to natural vegetation (distance from the middle of the rooibos field to the nearest natural vegetation) were determined using GPS co-ordinates, 1:50 000 maps and satellite photographs (Google Earth images). The percentage natural vegetation surrounding each rooibos field, for each specified circle radii, was determined as the area surrounding the rooibos fields that is not under cultivation and that has not been developed, i.e. still natural vegetation. The areas under consideration did not overlap, as the distance between sites was larger than 5 km.

Floral resources

Floral resources were measured as diversity and abundance of plants in flower in spring (Sept 2008), summer (Dec 2008) and autumn (Mar 2009) along each transect of each location. Floral cover was determined as the percentage cover of flower corollas per ground surface area measured by multiplying the two larger linear dimensions of the flower (inflorescence) by the number of flowers (inflorescences) per plant (Moldenke, 1975; Tepedino and Stanton, 1982). The spring field visit comprised two visits to include peak spring flowering of annuals and many perennials (mid-Sept) and peak rooibos flowering time (usually mid-Oct). Plants in flower were identified using field guides (Manning and Goldblatt, 1997; Van Rooyen and Steyn, 1999) or by using keys for the Cape Floristic Region (Goldblatt and Manning, 2000) and/or interactive identification keys for ericas (Volk and Forshaw, 2004) and succulents (Interactive mesembs, SANBI database). Plant nomenclature followed Germishuizen and Meyer (2003).

Insect diversity and abundance

Insect abundance and diversity surveys were conducted at four sites (sites 6, 9, 10 and 11) from Dec 2008, for one year. Sites were selected to include study areas with and without strips as well as sites organically and conventionally farmed (Table 1). Yellow delta traps (110 x 200 x 280 mm) containing sticky liners (from Insect Science™) were placed on wooden poles 30 cm above rooibos height, in order for AP to see the traps above the rooibos plants. These traps were set up in triplicate at each site's locations (n = 39) and left for 9 weeks after which the liners were collected and assessed for abundance of pollinating taxa (bees and wasps) as well as diversity of all insects (Fig. 4). The traps were removed and re-set four times with 3 month intervals between removals. Representative samples of each insect species were removed from the sticky liners, pinned and recognizable taxonomic units (RTUs) were identified. Insects were identified to order level using field guides (Holm and De Meillon, 1995; Michener, 2000; Picker *et al.*, 2004), keys for Southern African insects (Scholtz and Holm, 1985) and/or interactive identification keys for insect identification (http://www.insectidentification.net, http://bugguide.net).

Insect abundance was calculated as the total number of individuals collected and bee/wasp abundance was calculated as the total number of bee/wasp individuals collected. Insect species diversity was calculated as the total number of RTUs collected and bee/wasp species diversity was calculated as the total number of bee/wasp RTUs collected. References made to bees or wasps refer to all members of bees and wasps in the order Hymenoptera.

Statistics

To determine whether environmental variables such as rainfall, elevation, slope and aspect contributed to the plant diversity and abundance (i.e. whether or not sites can be compared directly) a RA (distance biplot, Twinspan dendogram) and GLM were used (see Preliminary analysis of regions).

Data were analysed by comparing different locations, i.e. rooibos fields, natural vegetation and vegetation strips between sites (n = 13 pairs) per season. Data were also analysed by comparing data across different seasons. Where appropriate, I tested data for normality and equality of variances before using parametric analyses. Deviations from normality were assessed using the Shapiro-Wilk's W-test (Holm and De Meillon, 1995). The results of these preparatory tests are not reported when inductive parametric statistics are used. When data were transformed, these transformations are reported. All parametric results were assessed for homoscedasticity in the residual scatter plot.

Normally distributed data were analysed using factorial ANOVAs (with replication) whereas Kruskal Wallis was used for non-normal data. For all repeated Student's t-tests, a Sequential Bonferroni correction was applied to correct for false detection rates (Cabin and Mitchell, 2000). Correlation was assessed using Product-Moment and partial correlation methods for normal data and Spearman-rank for non-normal or count data. Percentage natural vegetation and proximity to natural vegetation were tested using a Student's t-test for variation between sites at the three different scales. Floral resources, insect (bee and wasp) diversity and abundance, and seed set were also compared using a Student's t-test and Chi-Square for on-site differences as well as differences owing to farming practices (organic *vs.* conventional). Variation between sites and seasons in floral resources and insect (bee and wasp) abundance and diversity were tested using a factorial ANOVA (with replication) and single factor ANOVA. Causes of significant differences were identified using a post-hoc Tukey HSD test. All tests were conducted at a 5% level of significance in Statistica Version 9.0 (StatSoft Inc., 2009).

Results

Variation due to environmental factors was not significant, explaining less than 1% ($p > 0.05$) of the variation in floral resources and insect abundance/diversity between sites. The highest contribution to the total variance in the model was explained by altitude and

MAP. Altitude explained 0.06% (RA) to 0.79% (GLM) of the variance while variance due to MAP was 0.02% (RA) to 0.97% (GLM).

Since this preliminary statistical analysis showed no difference between altitude, rainfall, temperature and floral cover between the northern (Nieuwoudtville, sites 1 to 9) and southern (Clanwilliam, sites 10 to 13) sites, I considered these sites comparable for this study.

Rooibos pollinators

Flower formation as well as seed set was determined and compared between bags that were open (allowing AP access) and bags that were closed (denying AP access). During the experiment, a total of 40 (16.7%) of the bags were dislodged or on plants that died.

Floral formation in open *vs.* closed bags did not differ significantly ($p > 0.05$). Seed (pod) formation showed a marked difference ($p < 0.001$) between open and closed pollination bags with up to 25 times more seeds formed in open bags compared to closed bags. Pollination efficiency was consistently low for closed pollination bags on all sites (between 2.4 and 6.3%) while there was far more variation in seed set evident for open pollination bags at the four sites. The pollination efficiencies of the open and closed bags varied significantly (Chi-Square, df = 89, $p < 0.001$) with open bags having 10 times higher pollination efficiency rates in some instances (Fig. 5). This indicates that rooibos is pollinated to a great extent by flying insects and that rooibos has an extremely limited self-pollination potential.

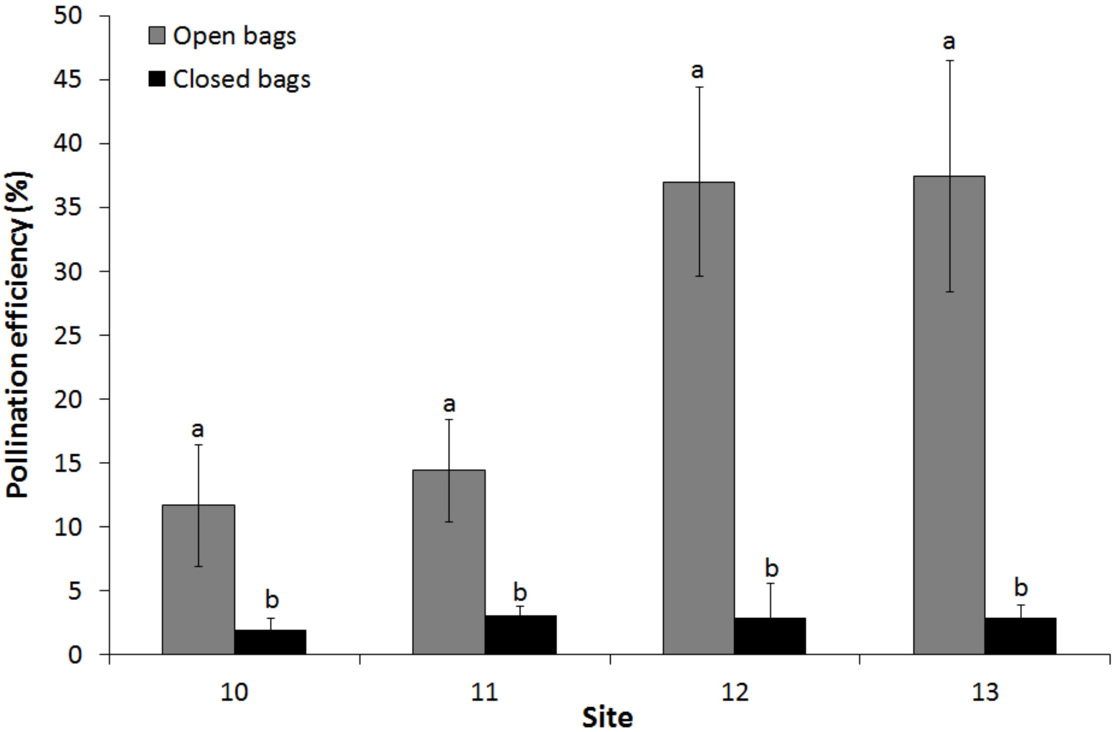

Fig. 5. Pollination efficiency rates (open and closed bags) of the four Clanwilliam sites (sites 10 to 13). Values are means ± se. Different letters indicate a significant difference at the $p < 0.05$ level.

Availability of natural vegetation and floral resources

There was considerable variation in percentage natural vegetation over the three different scales, with percentage natural vegetation varying between 0 to 92%, 17 to 98% and 32 to 95%, at scales of 500, 1000 and 3000 m, respectively. At the 13 study sites the percentage natural vegetation surrounding fields increased as the radius of measurement around the farm increased. Field size was also very variable, with the smallest fields being 50 m in diameter, and the largest having a diameter 20 times greater, at 1067 m (Table 2).

There was no correlation between flower cover/diversity and percentage natural vegetation at a local scale, i.e. 500 m radius, but floral cover in fields surveyed increased with increasing natural vegetation cover at a landscape scale, i.e. 1000 and 3000 m ($r = 0.14$, $p = 0.038$ and $r = 0.15$, $p = 0.025$, respectively). There were no significant differences in floral cover within rooibos fields compared to within natural vegetation at the same site (Table 3, paired t-tests: $p > 0.05$) except for site 11 ($p = 0.014$) and 10 ($p = 0.009$) which had a significantly higher floral cover in the rooibos fields (compared to natural vegetation) in spring.

Table 2. Field diameter and landscape composition at different scales for 13 sites at rooibos farms.

Site no.	Strips present	Farming type	Field size (diameter, m)	Surrounding vegetation cover		
				500 m radius	1000 m radius	3000 m radius
1	No	Conventional	326	58	78	77
2	Yes	Organic	213	75	83	92
3	Yes	Organic	131	79	89	95
4	No	Organic	124	71	76	94
5	No	Conventional	178	83	57	81
6	No	Organic	50	33	57	81
7	No	Organic	114	92	83	81
8	Yes	Conventional	277	63	74	74
9	Yes	Organic	52	92	98	92
10	No	Conventional	1012	0	22	51
11	Yes	Conventional	1045	17	28	55
12	No	Conventional	1067	8	35	67
13	No	Conventional	700	4	17	32

Table 3. Floral cover over three seasons (spring: Oct 2008, summer: Dec 2008 and autumn: Mar 2009) on selected sites. Values are means ± standard error and p-values are the result of a Student's t-test between locations. Zero values indicate the absence of any floral cover in that location; negative values for difference indicate a higher floral cover in rooibos fields compared to the natural vegetation.[6]

	Floral cover (m^2)			
Site no.	**Vegetation**	**Rooibos**	**Difference**	**p-value**
Summer				
6	0.05 ± 0.01	0.28 ± 0.04	-0.23	0.441
9	0.00 ± 0.00	0.08 ± 0.01	-0.08	0.094
10	0.23 ± 0.06	0.00 ± 0.00	+0.23	0.299
11	0.05 ± 0.01	0.01 ± 0.00	+0.04	0.231
Autumn				
6	1.02 ± 0.33	1.01 ± 0.33	0.00	0.999
9	2.44 ± 0.74	0.00 ± 0.00	+2.44	0.129
10	0.00 ± 0.00	0.00 ± 0.00	0.00	-
11	0.00 ± 0.00	0.00 ± 0.00	0.00	-
Spring				
6	34.52 ± 0.39	40.89 ± 6.40	-6.37	0.207
9	27.08 ± 0.19	38.16 ± 6.62	-11.08	0.308
10	34.59 ± 9.12	18.07 ± 1.62	+16.52	0.009
11	1.63 ± 0.14	4.99 ± 0.28	-3.36	0.014

In the summer season all the sites in the Clanwilliam area (sites 10 to 13) had similar floral cover in the natural vegetation (total cover: 0.23, 0.05, 0.63 and 0.85 m² per site respectively) compared to the rooibos fields (total cover: 0.00, 0.01, 0.09 and 0.01 m² per site, respectively). There was also no significant difference in the floral resource cover between Nieuwoudtville sites (1.32 m² per site) and Clanwilliam sites (1.48 m² per site). Similar trends were observed for the remainder of the year. Floral resources varied

[6] Only data for sites on which insect sampling surveys were conducted are shown here. Other sites show similar results and selected data is given in the text where relevant to general trends.

significantly between seasons for both natural vegetation ($p < 0.001$) and rooibos fields ($p < 0.001$) with the highest floral resources being available in spring. Strip presence, i.e. proximity to natural vegetation, was significantly correlated with floral diversity within rooibos fields ($r = 0.16$, $p = 0.015$) but not with floral cover ($r = 0.04$, $p = 0.524$).

Pollinator presence and landscape scale

In the summer season, the mean abundance of insects collected per site was 73.18 ± 9.68 per delta trap ($n = 39$) with the highest abundance recorded at site 9 (88.89 ± 9.09 per delta trap) and the lowest at site 6 (45.00 ± 10.34 per delta trap). In the autumn, these numbers dropped significantly ($p < 0.05$) to a mean of 46.66 ± 6.80 insects collected per site. During autumn, site 10 had the greatest abundance of insects (60.22 ± 6.49 per delta trap) whereas site 6 had the fewest (28.83 ± 8.15 per delta trap). Overall mean wasp abundance for all sites decreased significantly ($p < 0.001$) from summer to autumn (36.92 ± 6.61 and 14.29 ± 3.06 per site respectively) whereas the diversity of bees increased significantly ($p < 0.001$) from summer to autumn (2.96 ± 0.44 and 4.35 ± 0.54 per site respectively).

Surrounding natural vegetation correlated positively using Spearman Rank with bee and wasp abundance as well as diversity (Table 4). Wasp abundance showed a decreasing trend with floral cover (Spearman Rank $R = -0.46$, $t = -2.40$, $p = 0.025$; Fig. 6). No correlation could be found between annual and perennial cover and bee and wasp abundance. Strong statistically significant increasing trend were found between percentage natural vegetation cover and bee/wasp abundance and diversity, at all spatial scales investigated (Figs. 7 and 8, Table 4).

Table 4. Spearman Rank correlations between percentage natural vegetation at different spatial scales, and bee/wasp abundance and diversity at four sites (sites 6, 9, 10 and 11). NS = not significant. Results reported after a Sequential Bonferroni correction was applied.

	R	**P**
3000 m radius		
Bee abundance	0.72	< 0.001
Bee diversity	0.84	<0.001
Wasp abundance	0.72	NS
Wasp diversity	0.60	NS
1000 m radius		
Bee abundance	0.72	< 0.001
Bee diversity	0.84	< 0.001
Wasp abundance	0.72	< 0.05
Wasp diversity	0.60	< 0.05
500 m radius		
Bee abundance	0.72	< 0.001
Bee diversity	0.84	< 0.001
Wasp abundance	0.72	< 0.05
Wasp di	0.60	< 0.05

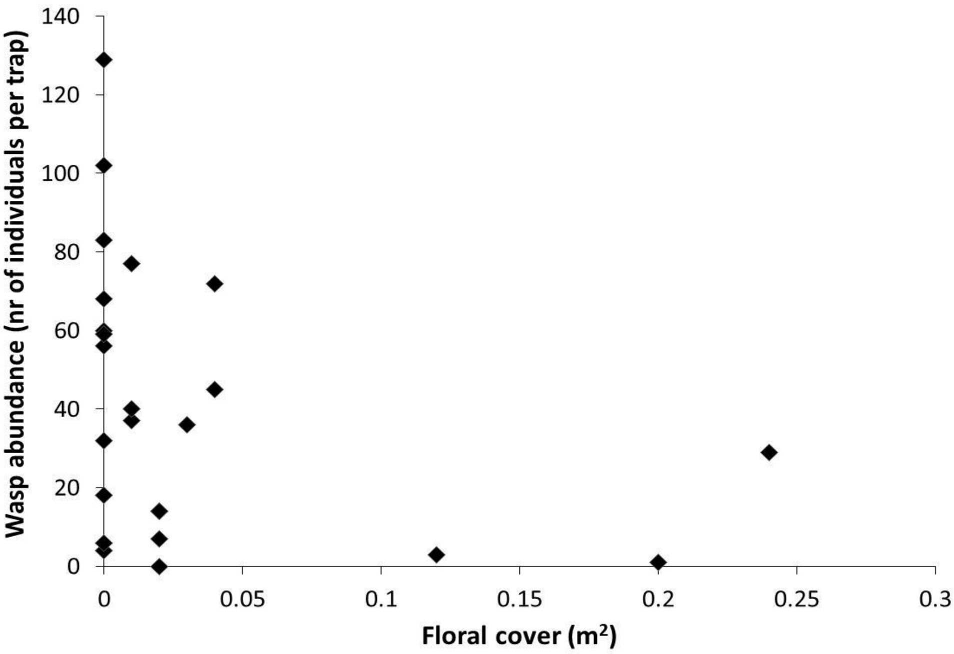

Fig. 6. Decreasing trend of wasp abundance with floral cover on selected sites (sites 6, 9, 10 and 11) from Dec 2008 to Sept 2009.

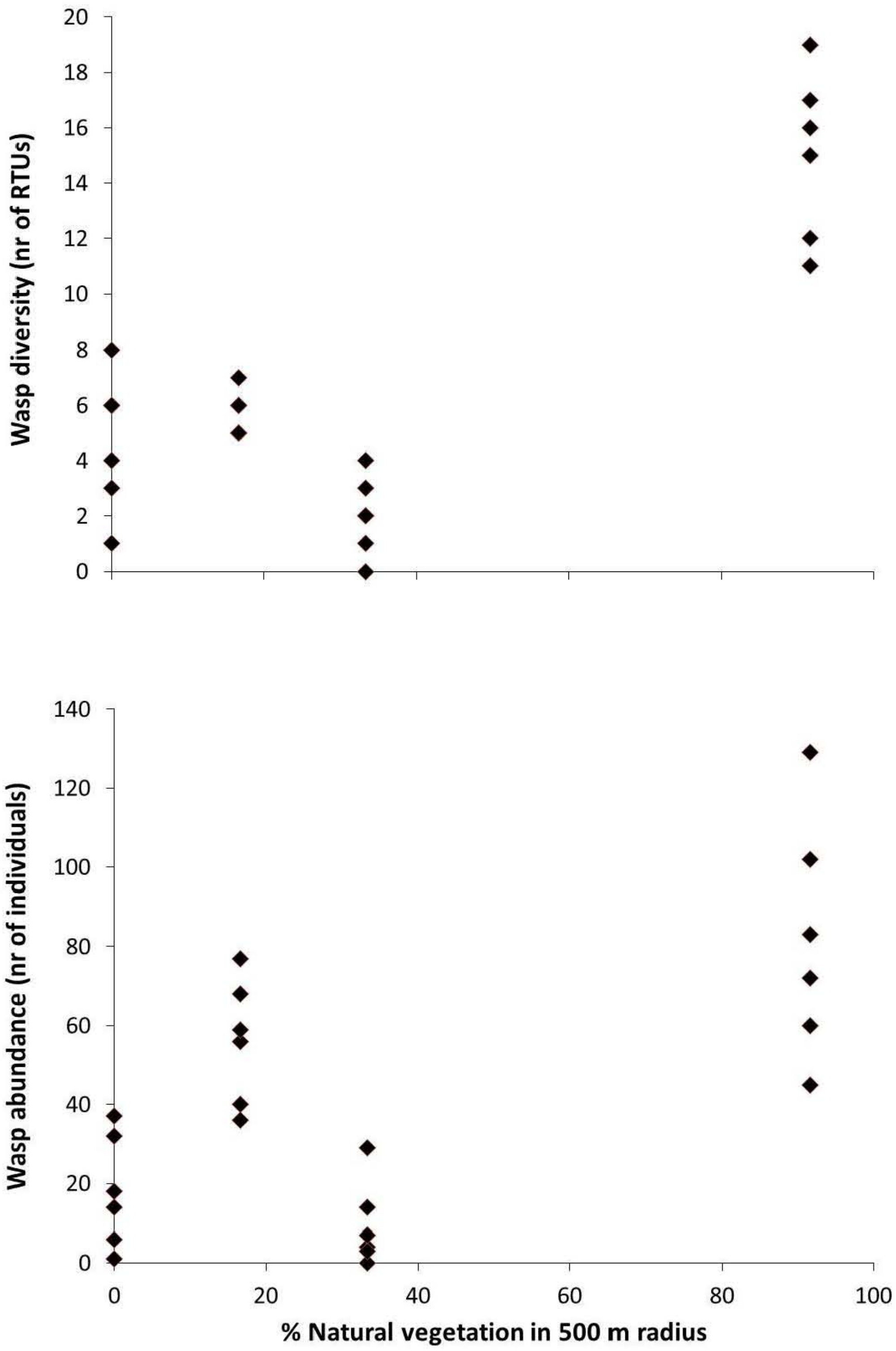

Fig. 7. Increasing trend between landscape context (percentage natural vegetation in a 500 m radius) and wasp diversity (top) and wasp abundance (bottom) on selected sites (sites 6, 9, 10 and 11) from Dec 2008 to Sept 2009.

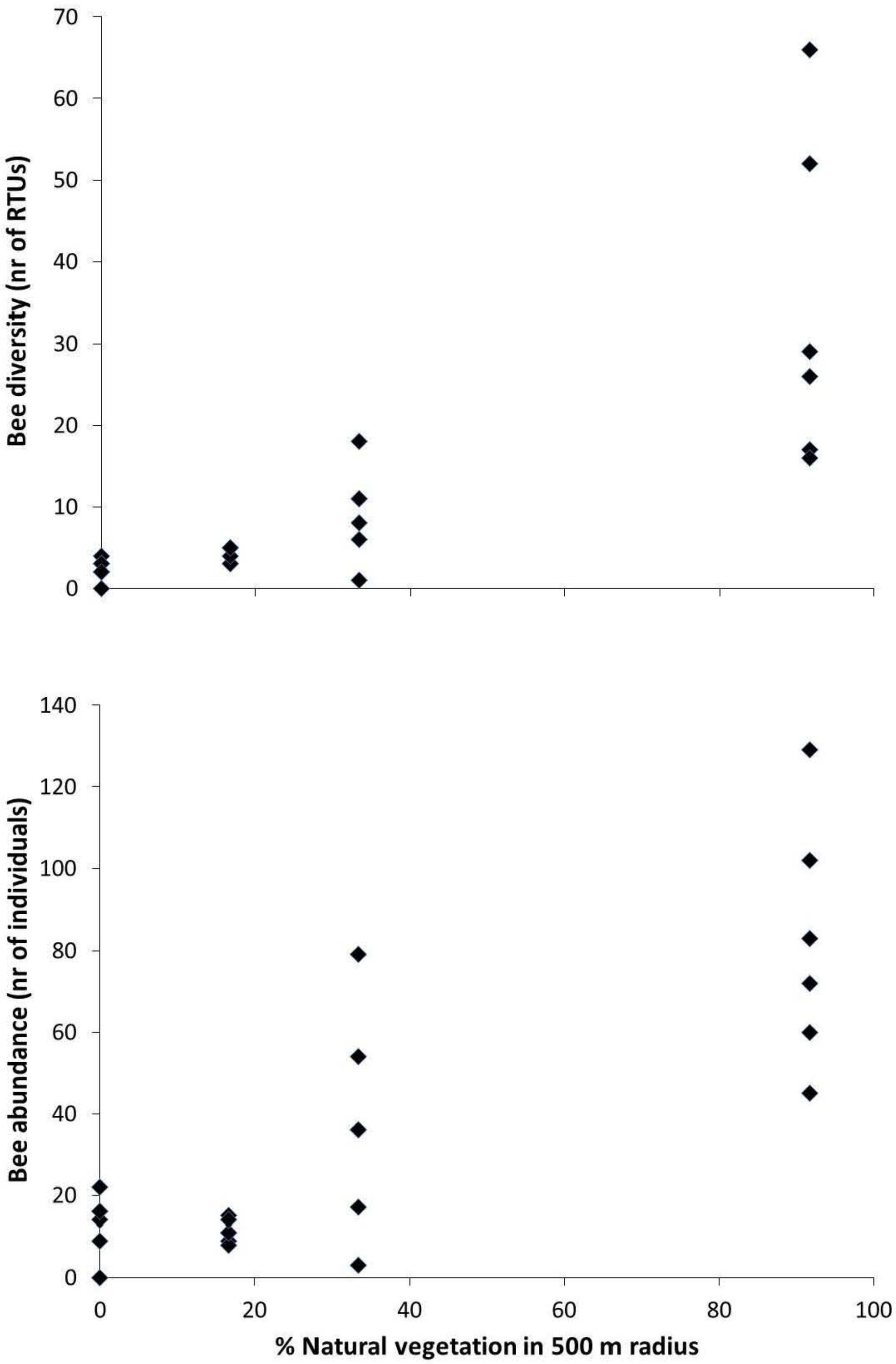

Fig. 8. Increasing trend between landscape context (percentage natural vegetation in a 500 m radius) and bee diversity (top) and bee abundance (bottom) on selected sites (sites 6, 9, 10 and 11) from Dec 2008 to Sept 2009.

Pollinator presence and proximity to natural habitat / presence of strips

Flower visitor abundance and diversity were compared in summer and autumn between the middle and edges of rooibos fields (sites 6, 9, 10 and 11), such that there was a gradient of proximity to natural vegetation across the farms, as field size varied between 50 and 1000 m (Table 2). Insect species diversity sampled in the middle of rooibos fields was far more variable in autumn than summer, ranging from 11 to 19 per site (summer) and 3 to 92 per site (autumn). On the edge of rooibos fields, this variability was less marked, ranging from 10 to 21 per site (summer) and 3 to 23 per site (autumn). On all sites except one, insect diversity was higher on the edges than in the middle of the rooibos field. Bee and wasp abundance and diversity correlated positively (i.e. increasing trend) with proximity to natural vegetation with Spearman Rank (Table 5).

Table 5. Spearman Rank correlations between proximity to natural vegetation and abundance and diversity of bees and wasps on the four sites (sites 6, 9, 10 and 11, n = 13 for all tests). Results reported after a Sequential Bonferroni correction was applied.

	R	p-value
Bees		
Abundance	0.47	< 0.01
Diversity	0.69	< 0.001
Wasps		
Abundance	0.77	< 0.001
Diversity	0.66	< 0.001

Those sites for which the middle of the rooibos field was > 500 m to the nearest natural vegetation (sites 10 and 11) exhibited a 10 to 15% decrease in insect abundance and diversity in the middle of the fields compared to the edge. Only rooibos fields with strips present (sites 9 and 11) had similar insect diversity and abundance in the middle and the edge of the field (2 to 4% difference).

Effects of agrochemical use on floral cover and insect diversity and abundance

The total floral cover as well as annual and perennial floral cover (Srep), were compared between organic and conventional sites (Fig. 9) and all three comparisons showed significant differences (factorial ANOVA, N = 21, $p < 0.001$).

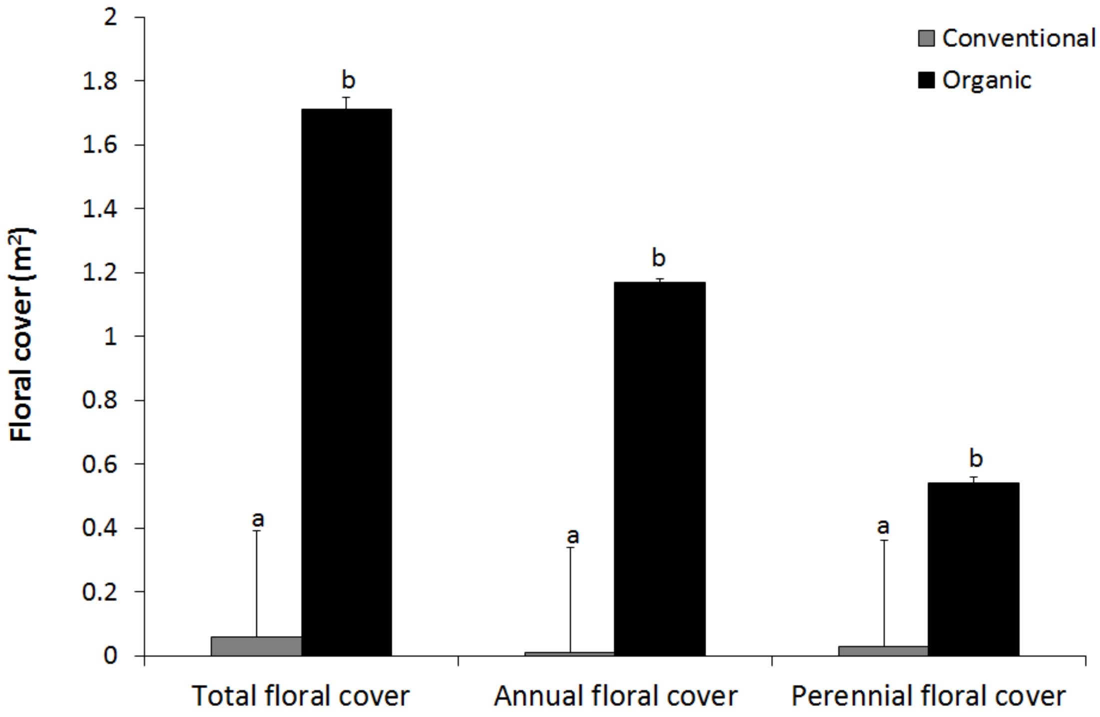

Fig. 9. Differences in total floral cover, annual floral cover and perennial floral cover during autumn on conventional and organic farmed sites (sites 1 to 13). Values are means ± se. Different letters indicate a significant difference at the p < 0.05 level.

In autumn, the floral cover on organiclly farmed sites was higher than on conventionally farmed sites (Fig. 9). This may partially but not completely explain the higher abundance and diversity of bees and wasps on organically *vs*. conventionally farmed sites (bees: $r = 0.78$, $p < 0.001$; wasps: $r = 0.89$, $p < 0.001$). This was also the case for the total number of bees and wasps (abundance) (bees: $r = 0.77$, $p < 0.001$; wasps: $r = 0.69$, $p < 0.001$). Across the seasons, bee abundance was higher on the organic sites (summer: 21.73 ± 4.34 per site;

autumn: 19.93 ± 3.75 per site) compared to conventional sites (summer: 11.71 ± 1.47 per site; autumn: 14.25 ± 2.06 per site).

Rooibos seed set

The contribution of insect pollinators to seed set was highest at sites closest to natural vegetation (49 and 75% for sites 12 and 13 respectively) and those sites with a lower proximity to natural vegetation having lower contribution of insect pollinators to seed set (35 and 47% for sites 10 and 11 respectively) (Fig. 10).

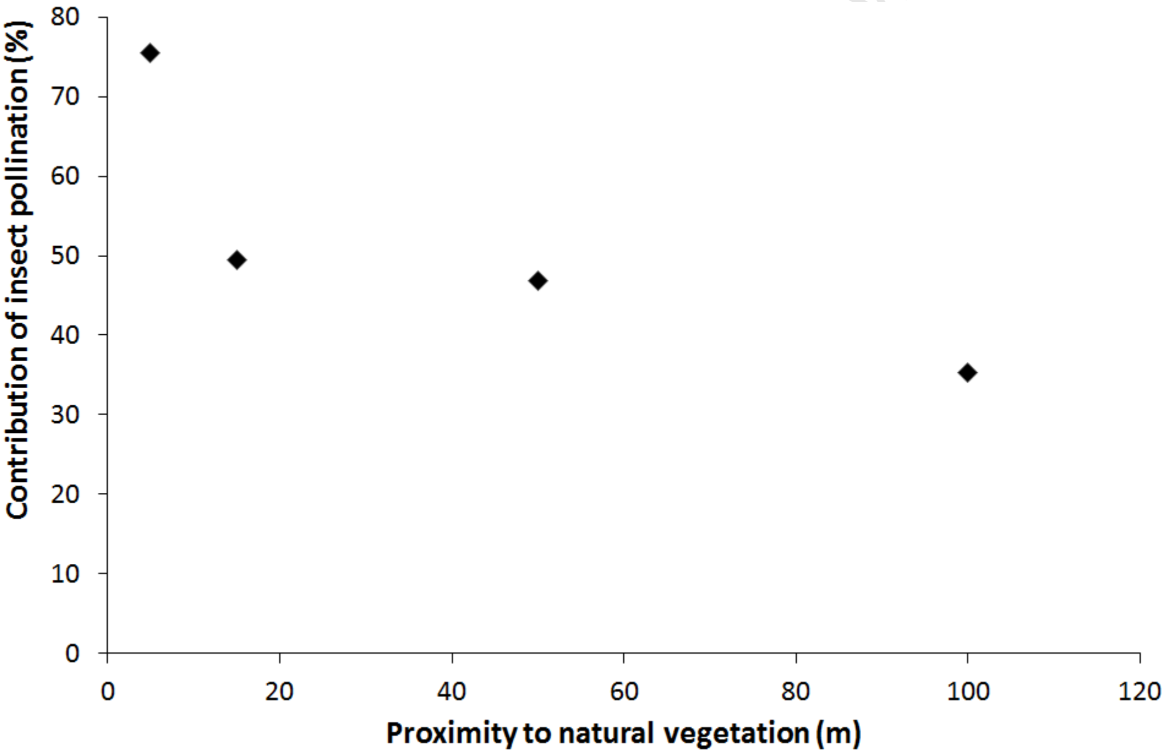

Fig. 10. Contribution of insect pollination (open and closed bags) of the four Clanwilliam sites (sites 10 to 13) relative to the proximity to natural vegetation of each site.

As mentioned earlier, the pollination efficiencies of the open and closed bags varied significantly (Chi-Square, $df = 89$, $p < 0.001$) with open bags having 10 times higher pollination efficiency rates in some instances (Fig. 5). Although the sample size (four sites) is too small to say with confidence that pollination efficiency increased as a function of proximity to natural vegetation, the trend suggests that this is the case (Fig. 10).

Discussion

In this study, I found that the natural environment is an important provider of ESS to rooibos farmers, as rooibos is pollinator dependent and insect abundance and diversity increased with availability of surrounding natural vegetation and in the absence of agrochemical usage. Furthermore, despite small sample sizes, the trend in seed set suggested that the importance of pollinators is reflected in actual rooibos seed set.

Until now, the dependence of rooibos on insect pollinators was unconfirmed, although suspected (Gess and Gess, 1994; Gess, 2000). The large and significant differences in seed set between open and closed pollination bags confirms that rooibos is dependent on flying insects for pollination. Given that access by crawling insect was eliminated in the open pollination bags, further evidence is provided that flying insect pollinators contribute greatly to rooibos pollination. Although initial number of flowers in open and closed pollinator exclusion bags was not different, pod production differed markedly between the two treatments. The pollination efficiencies of the open and closed bags varied significantly with open bags having 10 times higher pollination efficiency rates in some instances (Fig. 5) providing evidence that rooibos has extremely limited self-pollination potential. Although pod and seed formation in closed bags (insect excluded bags) did occur, many pods dropped before maturation and those that did develop fully exposed smaller, discolored seeds. Although the viability of seeds produced from open and closed bags was not tested, seeds from closed bags had a different appearance (i.e. discoloration, shriveled and smaller size) to viable rooibos seeds.

My investigations on landscape composition, i.e. percentage natural vegetation, strip presence, proximity to natural vegetation and floral resources, and pollinator presence provided evidence that insect abundance and diversity in rooibos fields are related to landscape composition, at all scales. Floral cover in fields surveyed increased with increasing natural vegetation cover at a landscape scale, i.e. 1000 and 3000 m, although it did not differ between rooibos fields and natural vegetation. The effect of large rooibos fields on insect (and therefore pollinator) abundance and diversity was marked in fields with radii > 500 m. Insect abundance and diversity were markedly different between natural vegetation and within rooibos fields. In smaller fields, edge effects were far less marked with many perennial plants found both on the edge and within rooibos fields. The surrounding vegetation of smaller fields was also dominated by rocks (in some cases > 50%) reducing the potential for vast amounts of flowering plants in these areas. Difficulty in ploughing this rocky area may explain why farmers have smaller (in some cases < 50 m radius) and more dispersed fields.

Taking into account the three different spatial scales (500, 1000 and 3000 m) on which the percentage natural vegetation was measured, only the 500 m radius provided a percentage surrounding vegetation cover ranging from zero to almost 92. Other scales provided limited ranges of percentage natural vegetation with the ranges becoming less varied as the radii increased. Gathmann and Tscharntke (2002) found that solitary bees (16 species investigated) have a maximum foraging distance of 150 to 600 m. Steffan-Dewenter *et al.* (2002) also found a positive correlation between wild bee abundance and diversity, and the percentage of semi-natural habitats at small scales (up to 750 m). Although I found significant trends between bee/wasp abundance and diversity, and proximity to natural vegetation on all spatial scales (Table 4), the highest diversity and abundance was found at a scale of 500 m. For these reasons I suggest that an optimal presence of pollinators, as well as other insects, can be found on rooibos fields with radii < 500 m.

As mentioned above, bee and wasp abundance and diversity showed an increasing trend with increased surrounding natural vegetation at all spatial scales (Figs. 7 and 8). Wasp abundance should a decreasing trend with floral cover throughout all seasons (Fig. 6) which could possibly indicate that the wasps tend to focus their foraging activities to more rewarding plants when fewer resources are available. In other words, wasps may congregate in areas where floral resources are more readily available during the drier months and are more dispersed (have larger foraging ranges) when more resources are available. Similar trends were found for bees although these trends were not statistically significant. Although this is a plausible scenario, only 16.81% of the variation is explained and further research will have to be conducted in order to investigate the negative correlation seen.

The determination of insect abundance was bias towards those insects attracted to yellow traps (yellow delta trap survey) as shown by Mayer (2005) and Westphal (2008) and the identification of insects into RTU's are a flawed approach. However, although the abundance determination and insect identification methods had limitations, due to the nature of the hypotheses presented, it was sufficient for a comparative analysis between sites.

My hypothesis that the abundance and diversity of insects (specifically Order Hymenoptera) increases with increasing percentage of natural habitats/vegetation in a landscape is supported, but the increase seems not to be due to floral resources. The increase in insect diversity and abundance seems to be best explained by the foraging distance of these insects. Rooibos fields from which the middle of the field is < 500 m to the nearest natural vegetation did not show any significant difference in the insect abundance or diversity between field edge and middle. Vegetation strips effectively reduce field size by providing habitat within fields, thus limiting the influence that foraging distance has on insects, enabling insects to forage even within large (> 500 m in diameter) fields both on the edge and in the middle. Thus our hypothesis that the abundance and diversity of insects (specifically Order Hymenoptera) increases with increasing proximity to natural habitat and the presence of natural vegetation strips was supported, and vegetation strips seem to offset the effect of large fields on insect diversity and abundance.

Many of the rooibos fields that had higher floral cover (annuals) within the cultivated fields during the rainy season are conventionally farmed and mechanically ploughed. This impacted the floral cover during the summer and autumn seasons with these sites (rooibos fields > 500 m radii and conventionally managed) having significantly less floral cover within rooibos fields compared to the surrounding vegetation. In essence, floral cover was highly variable in these sites, which might have implications for the invertebrate fauna within these areas. In autumn, when floral resources are at their lowest, the conventional sites had no flower cover (floral resources) in the rooibos, or in the natural vegetation (Table 3). These two factors (conventional farming and mechanical ploughing) probably explain the loss of geophyte bulbs and seeds resulting in low levels of biodiversity in the fields. This directly influences the resources available to insects during the remainder of the year, i.e. out of the annual rainy season. In addition, insect pollinators need to be viewed in terms of their full life cycles, and ploughing disturbs the nest sites of many hole-nesting bees and ground-nesting wasps.

In my investigation into the effect of farming practices on insect pollinators, the diversity of bee and wasp species as well as their abundance was far higher on the two organic farms compared to the two conventional farms. The diversity of flowering plants as well as wasp and bee diversity and abundance in rooibos fields varied with agrochemical (fertilizer, herbicides and pesticides) use, with highest diversity and abundance in organic fields. In autumn, organic rooibos fields had more than double the amount of flower cover on average than conventional rooibos fields (Fig. 9). Agrochemical use thus reduces the cover and diversity of flowering species in conventional fields and thereby the resource availability for flower-visiting bees and wasps throughout the site (i.e. rooibos field and natural vegetation). Contrary to expectations, insect abundance and diversity were not directly related to floral cover but rather to foraging distance. Thus it is likely that the absence of insecticides and possibly herbicides in organic fields, together with field size that affects insect populations the most. Insecticide use is considered as an important direct cause of bee mortality in agricultural regions (Thompson, 2003).

The exclusion bag experiments provided evidence that rooibos is indeed pollinated by flying insects. From this experiment, there was also a trend for higher pollination efficiency with proximity to natural vegetation. Since insect diversity and abundance were correlated with percentage of natural vegetation and also increased with proximity to natural vegetation, this is not particularly surprising, and supports the notion that proximity of rooibos fields to natural vegetation plays a significant role in the pollination and seed set of rooibos flowers. This is particularly important to rooibos farmers since rooibos plants are only propagated from seed at present.

In conclusion rooibos is most probably pollinated by flying insects from the order Hymenoptera (Gess and Gess, 1994) and that organic farming practices, as opposed to conventional farming systems, support pollination in rooibos fields to a greater extent. Rooibos fields in close proximity to natural vegetation, either surrounding fields or as strips within fields, assist in decreasing foraging distances for insects, increase bee/wasp diversity and abundance and thus increase rooibos seed set. Strip presence also assists in decreasing foraging distances for insects thus increasing insect abundance in rooibos fields. It is recommended to leave as much natural vegetation surrounding rooibos fields as possible since results from this study showed no leveling-off of insect abundance and diversity in 500 to 3000 m radii around sites. Field size should ideally be < 500 m from edge to middle as a marked decrease in insect abundance and diversity was found with fields with radii > 500 m.

References

AIZEN, M.A. & FEINSINGER, P. 1994. Habitat fragmentation, native insect pollinators, and feral honey bees in Argentine 'Chaco Serrano'. *Ecological Applications,* 4, 378-392.

ALLEN-WARDELL, G., BERNHARDT, P., BITNER, R., BURQUEZ, A., BUCHMANN, S., CANE, J., COX, P.A., DALTON, V., FEINSINGER, P., INGRAM, M., INOUYE, D., JONES, C.E., KENNEDY, K., KEVAN, P., KOOPOWITZ, H., MEDELLIN, R. & MEDELLIN-MORALES, S. 1998. The potential consequences of pollinator declines on the conservation of biodiversity and stability of food crop yields. *Conservation Biology,* 12, 8-17.

ALLSOPP, M. 2004. Cape honeybee (*Apis mellifera capensis* Eshscholtz) and varroa mite (*Varroa destructor* Anderson & Trueman) threats to honeybees and beekeeping in Africa. *International Journal of Tropical Insect Science,* 24, 87-94.

ANDERSON, D.L., SEDGLEY, M., SHORT, J.R.T. & ALLWOOD, A.J. 1982. Insect pollination of mango in northern Australia. *Australian Journal of Agricultural Research,* 33, 541–548.

CABIN, R.J. & MITCHELL, R.J. 2000. To Bonferroni or not to Bonferroni: When and how are the questions. *Bulletin of the Ecological Society of America,* 81, 246-248.

CARVALHEIRO, L.G., SEYMOUR, C.L., VELDTMAN, R. & NICOLSON, S.W. 2010. Pollination services decline with distance from natural habitat even in biodiversity-rich areas. *Journal of Applied Ecology*.

CUNNINGHAM, S.A. 2000. Depressed pollination in habitat fragments causes low fruit set. *Proceedings of the Royal Society Biological Sciences Series B,* 267, 1149.

DAVISON, S., LEAT, N. & BENJEDDOU, M. 2003. Development of molecular tools for honeybee virus research: The South African contribution. *African Journal of Biotechnology,* 2, 698-713.

DIEKÖTTER, T., WALTHER-HELLWIG, K., CONRADI, M., SUTER, M. & FRANKL, R. 2006. Effects of landscape elements on the distribution of the rare bumblebee species Bombus muscorum in an agricultural landscape. *Biodiversity and Conservation,* 15, 57-68.

DONALDSON, J.S. 1999. Conservation of globally significant biodiversity in agricultural landscapes in South Africa through conservation farming. *Global Environmental Facility Targeted Research Proposal.* Cape Town: National Botanical Institute.

DONALDSON, J.S. 2002. Pollination in agricultural landscapes, a South African perspective. *In:* KEVAN, P. & IMPERATRIZ FONSECA, V.L. (eds.) *Pollinating Bees - The Conservation Link Between Agriculture and Nature.* Brasília: Ministry of Environment.

GATHMANN, A. & TSCHARNTKE, T. 2002. Foraging ranges of solitary bees. *Journal of Animal Ecology,* 71, 757-764.

GERMISHUIZEN, G. & MEYER, N.L. (eds.) 2003. *Plants of southern Africa: An annotated checklist.* Pretoria: National Botanical Institute.

GESS, F.W. & GESS, S.K. 1993. Effects of increasing land utilization on species representation and diversity of aculeate wasps and bees in the semi-arid areas of Southern Africa. *In:* LASELLE, J. & GAULD, I.D. (eds.) *Hymenoptera and biodiversity*. Wallingford: CAB International.

GESS, S.K. 2000. Rooibos, refreshment for humans, bees and wasps – The flower visitors and pollinators of Aspalathus. *Veld & Flora.*

GESS, S.K. & GESS, F.W. 1994. Potential pollinators of the Cape Group of Crotalarieae (sensu Polhill) (Fabales: Papilionaceae), with implications for seed production in cultivated rooibos tea. *African Entomology,* 2, 97-106.

GHAZOUL, J. 2005. Buzziness as usual? Questioning the global pollination crisis. *Trends in Ecology & Evolution*, 20, 367-373.

GOLDBLATT, P. & MANNING, J. 2000. *Cape Plants: A conspectus of the Cape flora of South Africa.* Cape Town: National Botanical Society of South Africa and USA, Missouri Botanical Garden, MGB Press.

GREENLEAF, S.S., WILLIAMS, N.M., WINFREE, R. & KREMEN, C. 2007. Bee foraging ranges and their relationship to body size. *Oecologia*, 153, 589–596.

HAWKINS, H.-J., MALGAS, R.R. & BIENABE, E. 2010. Ecotypes of wild rooibos (*Aspalathus linearis* (Burm. F) Dahlg., Fabaceae) are ecologically distinct. *South African Journal of Botany*, in press.

HEARD, T.A. & EXLEY, E.M. 1994. Diversity, abundance, and distribution of insect visitors to macadamia flowers. *Environmental Entomology*, 23, 91–100.

HEARD, T.A., VITHANAGE, V. & CHACKO , E.K. 1990. Pollination biology of cashew in the Northern Territory of Australia. *Australian Journal of Agricultural Research,* 41, 1101-1114.

HOLM, E. & DE MEILLON, E. 1995. *Pocket guide to insects of southern Africa.* Hartebeespoort: Ekogilde.

HOLZSCHUH, A., STEFFAN-DEWENTER, I., KLEIJN, D. & TSCHARNTKE, T. 2007. Diversity of flower-visiting bees in cereal fields: Effects of farming system, landscape composition and regional context. *Journal of Applied Ecology*, 44, 41-49.

KIM, J., WILLIAMS, N.M. & KREMEN, C. 2006. Effects of cultivation and proximity to natural habitat on ground-nesting native bees in California sunflower fields. *Journal of the Kansas Entomological Society,* 79.

KLEIN, A.M., STEFFAN-DEWENTER, I. & TSCHARNTKE, T. 2003. Pollination of Coffea canephora in relation to local and regional agroforestry management. *Journal of Applied Ecology*, 40, 837-845.

KREMEN, C. Year. Pollination services and community composition: Does it depend on diversity, abundance, biomass or species traits? *In:* FREITAS, B.M. & PEREIRA, J.O.P., eds. Solitary Bees . Conservation, Rearing and Management for Pollination, 2004 2004 Beberibe, Ceará, Brazil.

KREMEN, C. & RICKETTS, T. 2000. Global perspectives on pollination disruptions. *Conservation Biology*, 14, 1226-1228.

KREMEN, C., WILLIAMS, N.M., BUGG, R.L., FAY, J.P. & THORP, R.W. 2004. The area requirements of an ecosystem service: Crop pollination by native bee communities in California. *Ecology Letters*, 7, 1109-1119.

KREMEN, C., WILLIAMS, N.M. & THORP, R.W. 2002. Crop pollination from native bees at risk from agricultural intensification. *Proceedings of the National Academy of Sciences of the United States of America,* 99, 16812–16816.

KRUESS, A. & TSCHARNTKE, T. 2000. Species richness and parasitism in a fragmented landscape: Experiments and field studies with insects on Vicia sepium. *Oecologia*, 122, 129-137.

LUIG, J., PETERSON, K. & POLTIMÄE, H. 2005. Human impacts on pollinators and pollination services. *ALARM Socio-economic Working Paper.*

MANNING, J. & GOLDBLATT, P. 1997. *Nieuwoudtville, Bokkeveld Plateau and Hantam.* Cape Town, South Africa: Botanical Society of South Africa.

MAYER, C. 2005. Does grazing influence bee diversity? *In:* HUBER, B.A., SINCLAIR, B.J. & LAMPE, K.-H. (eds.) *African Biodiversity: Molecules, Organisms, Ecosystems.* Museum Koenig, Bonn: Springer.

MICHENER, C.D. 2000. *The bees of the world.* Baltimore, Maryland, USA: The John Hopkins University Press.

MOLDENKE, A.R. 1975. Niche Specialization and Species Diversity along a California Transect. *Oecologia*, 21, 219-242.

NABHAN, G.P. & BUCHMANN, S.L. 1997. Pollination services: Biodiversity's direct link to world food stability. *In:* DAILY, G. (ed.) *Nature's Services: Societal Dependence on Natural Ecosystems.* Washington, D.C.: Island Press.

PICKER, M., GRIFFITHS, C. & WEAVING, A. 2004. *Field guide to insects of South Africa.* Cape Town: Struik Publishers.

RAIESI, F. & GHOLLARATA, M. 2006. Interactions between phosphorus availability and an AM fungus (*Glomus intraradices*) and their effects on soil microbial resperation, biomass and enzyme activities in a calcareous soil. *Pedobiologia*, 50, 413-425.

RICKETTS, T.H. 2001. The matrix matters: Effective isolation in fragmented landscapes. *American Naturalist*, 158, 87-99.

RICKETTS, T.H. 2004. Tropical forest fragments enhance pollinator activity in nearby coffee crops. *Conservation Biology*, 18, 1262-1271.

SAUNDERS, D.A., HOBBS, R.J. & MARGULES, C.R. 1991. Biological consequences of ecosystem fragmentation: A review. *Conservation Biology*, 5, 18-32.

SCHOLTZ, C.H. & HOLM, E. 1985. *Insects of southern Africa.* Durban: Butterworths.

SCHULZE, R.E., MAHARAJ, M., LYNCH, S.D., HOWE, B.J. & MELVIL-THOMSON, B. 2000. *South African Atlas of Agrohydrology and Climatology*. Pretoria: Water Research Commission.

STATSOFT INC. 2009. STATISTICA (data analysis software system). 9.0 ed. Tulsa, USA.

STEFAN-DEWENTER, I. 2002. Landscape context affects trap-nesting bees, wasps, and their natural enemies. *Ecological Applications*, 27, 631-637.

STEFFAN-DEWENTER, I., MUNZENBERG, U., BURGER, C., THIES, C. & TSCHARNTKE, T. 2002. Scale-dependent effects of landscape context on three pollinator guilds. *Ecology*, 83, 1421-1432.

STEFFAN-DEWENTER, I. & TSCHARNTKE, T. 1999. Effects of habitat isolation on pollinator communities and seed set. *Oecologia*, 121.

TEPEDINO, V.J. & STANTON, N.L. 1982. Estimating Floral Resources and Flower Visitors in Studies of Pollinator-Plant Communities. *Oikos*, 38, 384-386.

THOMPSON, H.M. 2003. Behavioural effects of pesticides in bees: Their potential for use in risk assessment. *Ecotoxicology*, 12, 317-330.

VAN ROOYEN, G. & STEYN, H. 1999. *Cederberg, Clanwilliam and Biedouw valley.* Cape Town: Botanical Society of South Africa.

VOLK, F. & FORSHAW, N. 2004. Erica identification v. 2. *Contributions from the Bolus Herbarium*, 22.

WESTPHAL, C., BOMMARCO, R., CARRE, G., LAMBORN, E., MORISON, N., PETANIDOU, T., POTTS, S.G., ROBERTS, S.P.M., SZENTGYORGYI, H., TSCHEULIN, T., VAISSIERE, B.E., WOYCIECHOWSKI, M., BIESMEIJER, J.C., KUNIN, W.E., SETTELE, J. & STEFFAN-DEWENTER, I. 2008. Measuring bee diversity in different European habitats and biogeographical regions. *Ecological Monographs*, 78, 653-671.

Chapter 3

PROXIMITY TO NATURAL VEGETATION REGULATES WIND ON ROOIBOS FARMS

Abstract

Although various studies have investigated the negative impacts of agricultural activities and agrochemical use on ecosystem services delivered by natural vegetation, these impacts have not been assessed for the low-input indigenous crop *Aspalathus linearis* (rooibos). In this study, I investigated the effects of landscape composition, natural vegetation proximity and rooibos production practices on selected regulating (wind, soil moisture and air temperature control) and one supporting ecosystem service (nutrient cycling measured as soil nutrient concentrations) in the Nieuwoudtville and Clanwilliam rooibos production areas of South Africa. Results indicate that organic farming practices, as opposed to conventional farming systems, resulted in 10 to 20% increased organic and total soil nitrogen concentrations and up to 40% decreased phosphate in rooibos fields. Contrary to the case in many organic farms where increased soil organic matter resulted in increased soil moisture retention, no difference in soil volumetric water content was found on organic (29.46%) and conventionally farmed sites (18.84%). The pH in the rooibos fields was higher than that in the natural vegetation; while rooibos fields in close proximity to natural vegetation resulted in decreased pH ($r = 0.92$, $p = 0.01$). This is, however, not unexpected since rooibos is a nitrogen-fixing legume, and has been known to increase soil

pH by up to 3.5 units. Soil phosphate content increased as the proximity decreased ($r = 0.72$, $p = 0.02$). Close proximity to natural vegetation drastically reduced wind speeds (by up to two orders of magnitude) but did not affect air temperature or other soil nutrients inside rooibos fields. These results suggest that mechanical ploughing should be limited either through brush cutting or leaving remaining vegetation strips intact, as this provides wind protection and may result in less wastage and pollution by agrochemicals.

Introduction

The rooibos (*Aspalathus linearis* L.) industry is dependent on natural surrounding areas for various ecosystem services (ESS) (Hansen, 2006; Pretorius, 2008). Apart from provisioning ESS such as water provision, the rooibos industry also depends on natural areas for regulating ESS (regulation of soil moisture, wind speed and air temperature) as well as supporting ESS. The latter includes biotic services from insects (e.g. pollination, as discussed in Chapter 2) as well as abiotic services such as soil nutrient cycling. This chapter will specifically address the effect that proximity to natural vegetation and farming practices have on regulating (soil moisture, wind speed and air temperature) and supporting (soil nutrient cycling measured as soil nutrient concentrations) ESS from which the rooibos production industry benefits.

Rooibos is a nodulating shrub indigenous to the Cederberg and Bokkeveld areas of the Cape Province. These areas are mainly dominated by Cape Supergroup sandstone soils (commonly known as Fybos soils) which are predominantly deep sandy soils (Broquet, 1992). These soils are known to be acidic with low organic matter contents, which limits water holding capacity of these soils (Matson *et al.*, 1997), as well as low nutrient concentrations and are particularly limited in nitrogen (N) and phosphate (P) (Broquet, 1992; Cocks and Stock, 2001). Fynbos soils are also characterized by a low buffering capacity and low nitrification potential, are well-drained and highly susceptible to wind and water erosion (Michener, 2000). It is well-known that agricultural activities such as ploughing, burning, and construction have a detrimental effect on the environment (Pimentel *et al.*, 1995; Mader *et al.*, 2002) and this is exacerbated in hot, wind-blown areas with sandy soil such as in some rooibos production areas (Hansen, 2006; Pretorius, 2008; Archer *et al.*, 2009). Due to topography, wind erosion is seldom a problem in mountainous areas where rooibos grows but nearer the coast in the Sandveld, rooibos does occur naturally but to a lesser extent compared to mountainous areas. However, it is here that extensive cultivation of rooibos occurs due to easier farming conditions (being less rocky), and where farm and natural lands are susceptible to wind erosion, and drying of soil.

Wind erosion is currently the main cause of soil loss in rooibos production areas near the coast and a guideline and extension service called Right Rooibos (a partnership between the South African Rooibos Council and CapeNature) aims to reduce this threat and impact, as well as to advise on land stewardship and sustainable farming. Regarding wind, the guideline addresses: (i) rooibos field layout to restrict surface movement of soil particles due to wind; (ii) planting/leaving natural vegetation strips perpendicular to prevailing winds in order to act as wind breaks; (iii) suitable crop rotation systems; (iv) fallow lands, cultivation and/or grazing during periods of high winds and; (iv) conservation tillage practices (Pretorius, 2008; 2010). Presently, to reduce wind and water erosion, farmers in the sandy Sandveld areas of rooibos production use windbreaks between cultivated blocks, which comprise natural or planted vegetation between 5 to 10 m wide. It is not known whether these windbreaks are effective, nor is it known whether they provide other ESS as well, such as enhanced soil moisture retention and nutrient cycling. In mountainous areas in which rooibos mostly occurs naturally, water erosion is seldom a problem although guidelines for water usage and irrigation in rooibos fields exist (Pretorius, 2008; 2010). However, the high degree of legal and illegal vegetation clearing for rooibos fields and the non-compliance with guidelines surrounding crop rotation and fallow land is not only a concern in itself but has made water erosion another potential cause for soil loss.

Natural vegetation is the main source of ESS in nature and its distribution is largely dependent upon climate, i.e. the interplay between temperature and moisture availability (Stephenson, 1990; Raich and Tufekcioglu, 2000). The same is true for soil (soil moisture and soil respiration), and measuring natural vegetation coverage (also see Chapter 2) thus goes hand in hand with the measurement of soil moisture and air temperature (Raich and Schlesinger, 1992; Raich and Tufekcioglu, 2000). Water availability has been found to influence plant colonization and distribution in a number of plant niches (Silvertown *et al.*, 1999) and even small differences in soil moisture have significant influence on seed germination and thus floristic diversity (Vivian-Smith, 1997; Xiong *et al.*, 2003) while obviously also being important for the survival of rooibos as a crop. Regarding soil specifically, five different, but interlaced, ESS provided by soil occur: soil moderates water cycling and nutrient cycling, it retains and delivers nutrients, shelters seeds, and provides physical support to plants. Soil, together with microbes, also plays an important role in the decomposition of organic matter and wastes, rendering otherwise potentially dangerous pathogens, harmless (Daily, 1997; Daily *et al.*, 1997).

It is important to investigate the role surrounding natural vegetation plays in providing the above ESS. Undisturbed vegetation represents the areas in which ESS occur naturally and in order to maintain the ESS in an area, it is thus important to protect the natural vegetation in that area (Hooper and Vitousek, 1997). Besides natural vegetation and strips, farming practices may also impact the ESS mentioned above. Some farming practices that may negatively affect ESS in areas of rooibos production include agrochemical use (causing changed or reduced abundance of helper bacteria and mycorrhiza, and competition from increased grass or alien vegetation due to fertilizer run-off), and ploughing (changed or reduced abundance of helper bacteria and mycorrhizal networks). Other farming practices may reinstate ESS, for example mulch, cover crops and the use of vegetation corridors and strips. These farming practices may help restore communities of soil microorganisms (e.g. N_2-fixing bacteria, mycorrhiza), plants and animals (O'Farrell *et al.*, 2007; Pretorius, 2010) and soil organic matter, which in turn could increase soil moisture retention (Matson *et al.*, 1997). Maintaining as much of the natural ESS as possible on farms will help to reduce fertilizer and water inputs which, in turn, will help maintain sustainable land use.

Organic farming practices are believed to be more environmentally friendly than conventional farming practices due to the absence of pesticides, herbicides and inorganic fertilizers while there is an emphasis on increasing soil carbon (C) through organic amendments which promotes soil microbe populations and thus soil nutrient cycling (Bengtsson *et al.*, 2005). The aim of organic agriculture is to enhance ESS that foster plant nutrition but simultaneously conserve soil and water resources (Pimentel *et al.*, 2005). Recent findings suggest that organic farming results in less erosion (Reganold *et al.*, 1987); higher C storage and less leaching of nutrients (Drinkwater *et al.*, 1995); and lower levels of pesticides in water systems (Mader *et al.*, 2002). It has also been argued that organic farming practices increase biological activity (Mader *et al.*, 2002) as well as overall agrobiodiversity and thus, the loss created by conventional farming practices (Stoate *et al.*, 2001; Benton *et al.*, 2003) could be partly ameliorated by the conversion from conventional to organic farming practices. Other farming methods that include biodiversity conservation are beginning to be practiced in various biodiversity and business initiatives globally and in South Africa (e.g. Fair Trade Original; Biodiversity and

Wine Initiative; Right Rooibos). These farming methods should also contribute to ESS but these initiatives are as yet in the beginning of the monitoring phase, with little data available.

In this study, I investigated the effects of natural vegetation proximity and rooibos production practices on selected regulating and supporting ESS. I hypothesized that:

1) Natural vegetation (as natural vegetation strips or surrounding vegetation) regulate wind, farm soil moisture and air temperature, and supports nutrient cycling, measured as soil nutrient concentrations; and

2) Organic (as opposed to conventional) rooibos production results in increased soil moisture and improved nutrient cycling (measured as soil nutrient concentrations).

The following are general objectives used to investigate the hypotheses:

- Organic (as opposed to conventional) rooibos production results in increased soil moisture and improved nutrient cycling (measured as soil nutrient concentrations);

- Rooibos fields with increased proximity to natural vegetation (either surrounding rooibos fields or as strips within rooibos fields) regulate wind, farm soil moisture and air temperature; and

- Natural vegetation in close proximity to rooibos fields, whether as strips within fields or vegetation surrounding the field, supports nutrient cycling (measured as soil nutrient concentrations).

Materials and Methods

Site characterization and assessment

Sites were classified according to proximity to natural vegetation (including vegetation strips) surrounding sites, as well as the type of farming practice (conventional or organic) used to produce rooibos (Table 1 and 2). At each site (n = 13), I sampled a rooibos field and adjacent natural vegetation, and where there were vegetation strips I also sampled these. Sites were categorized as organic or conventional based on the absence or use of agrochemicals (i.e. pesticides, insecticides and herbicides) respectively. I established a reference point in each location (i.e. rooibos field, natural vegetation or strip) and laid out three transects (see Chapter 1 – Specific study sites) such that there were six transects at each site without strips and nine transects at each site with strips. On each transect wind speed, soil VWC and soil nutrients were determined.

Soil nutrients

Four soil samples (comprising three pooled soil cores to 20 cm depth, 10 cm ∅) were collected at 5 m intervals along the central 25 m transect within the rooibos field and natural vegetation at each site (n = 8 per site). It was not logistically possible to measure nutrient cycling per se, and the nutrient status of the soils was thus determined by measuring soil nutrient concentrations. Air-dried, 2 mm sieved bulk soil samples were each analysed for pH, P (phosphate), C (carbon), total N (nitrogen), inorganic N (NO_3^-, Nitrate; NH_4^+, Ammonium) and organic N. Soil pH was determined by extracting 2 g soil in 20 ml 1 M KCl, shaking at 180 rpm for 60 min, centrifuging at 10 000 rpm for 10 min and measuring pH in the supernatant. Soil was prepared for P analysis by extracting 6.6 g soil in Bray II solution (Bray and Kurtz, 1945) before filtering and analysing using inductively coupled plasma atomic emission spectrometry (Varian Vista MPX ICP-AES, Australia). Soil C was determined using the Walkley-Black method (Nelson and Sommers, 1986). Soil total N was determined by combustion on a FP-528 Nitrogen Analyzer (Leco Corporation, St. Joseph, USA). Organic N was determined as the difference between total and inorganic N.

Soil volumetric water content

The soil volumetric water content (VWC; ratio of water volume to soil volume) was measured along each of the triplicate transects within each location at each site in spring (Sept 2008), summer (Dec 2008) and autumn (Mar 2009) using a time domain reflectrometry probe (Hydrosense, 120-mm probe, Campbell Scientific, Australia) using the method suggested by Ledieu et al. (1986). Five soil moisture readings (comprising three pooled readings each) were taken at 5 m intervals along each transect (n = 30 per site without strips and n = 45 per site with strips).

Temperature

Temperature within fields was measured in summer (Dec 2008), autumn (Mar 2009) and winter (Jul 2009) at selected sites. Pre-calibrated temperature data loggers (DS 1922L Thermochron iButtons®, Dallas SemiConductor, Maxim, Sunnyvale, CA) where placed on wooden stakes at *ca*. 1.3 m above ground level within the rooibos field and natural vegetation as well as in the vegetation strips, if they were present (N = 10 iButtons). Readings were taken at 90 min intervals to obtain a sample size of 1700 to 1800 readings, depending on number of days each iButton® was left in the field. I used the DS1921 Thermochron iButton® Software Download programme (Dallas SemiConductor, Maxim, Sunnyvale, CA) to download iButton® data. Readings (n = 1700 to 1800) were sorted according to date and mean maximum / minimum daily temperatures were obtained. All values are presented as mean ± se, N is the number of iButtons® and n is the number of measurements (or days, as indicated).

Wind speed

Wind speed was measured in spring (Sept 2008), summer (Dec 2008) and autumn (Mar 2009), within each of the triplicate transects in the natural vegetation and middle of the rooibos field using a hand-held anemometer (BTU Psychometer, AZ 8912) at *ca*. 1 m above ground level, i.e. height of rooibos plants. Five wind speed readings were determined (comprising four pooled readings were taken at 5 m intervals along transects (n = 30 per site). In addition, wind speed was also assessed using the tattering flag method (Pears, 1968) from Dec 2008, for 9 weeks. Unhemmed cotton squares (flags) were taped to wooden stakes 1 m above ground level, and the tattering rate (i.e. the difference in amount of fraying) of each flag was measured. This method was used by Lines and Howell (1963) who noted that the flags have the advantage of being able to integrate wind over time compared to the point measurements of anemometers. Tatter rates of flags were calibrated using on-farm weather stations where available. Four sites were selected and three flags were exposed at each location in conjunction with the reference points.

Statistics

To determine whether environmental variables such as rainfall, elevation, slope and aspect contributed to the plant diversity and abundance (i.e. whether or not sites can be compared directly) a RA (distance biplot, Twinspan dendogram) and GLM were used (see Chapter 2, Preliminary analysis of regions).

Data were analysed by comparing different locations: rooibos fields, natural vegetation and vegetation strips between sites (n = 13 pairs) in each season, i.e. spring (two visits: Sept 2008, Oct 2008), summer (Dec 2008) and autumn (Mar 2009). Data were also analysed by comparing data across different seasons. Where appropriate, I tested data for normality and equality of variances before using parametric analyses. Deviations from normality were assessed using the Shapiro-Wilk's W-test (Holm and De Meillon, 1995). The results of these preparatory tests are not reported when inductive parametric statistics are used. When data were transformed, these transformations are reported. All parametric results were assessed for homoscedasticity in the residual scatter plot.

Normally distributed data were analysed using factorial ANOVAs whereas Kruskal Wallis was used for non-normal data. To correct for false detection rates, a Sequential Bonferroni correction was applied for all repeated tests (e.g. Student's t-tests, correlations) (Cabin and Mitchell, 2000; Walsh, 2004). I tested for correlations between surrounding natural vegetation and nutrients, soil WVC, temperature and wind speed using Product-Moment and partial correlation methods. Soil nutrients and air temperature both within and between sites, and between farming practices were compared using a Student's t-test. Variation in soil VWC as well as wind speed was assessed using a factorial ANOVA (with replication), post-hoc Tukey HSD test and a Student's t-test. Results were considered significant at the 5% level in Statistica Version 9.0 (StatSoft Inc., 2009).

Results

A RA and GLM were used to determine the variation due to environmental factors between sites (see Chapter 2 – Methods). Since this preliminary statistical analysis showed no difference between altitude, rainfall, temperature and floral cover between the northern

(Nieuwoudtville, sites 1 to 9) and southern (Clanwilliam, sites 10 to 13) sites, I considered these sites comparable for this study (see Chapter 2 – Results).

Soil nutrients and agrochemical use

Soil nutrients were compared between locations (rooibos field and natural vegetation) as well as between organic and conventional sites. We found significant variations in total, inorganic and organic N between sites that differ in their management regimes. Total N (organic: 29.46 and conventional: 18.84 $mmol \cdot kg^{-1}$; $p < 0.001$), organic N (organic: 26.91 and conventional: 17.08 $mmol \cdot kg^{-1}$; $p < 0.001$) and NH_4^+ (organic: 1.59 and conventional: 0.80 $mmol \cdot kg^{-1}$; $p = 0.006$) was higher in the organic compared to conventionally farmed sites (Table 6). As could be expected, both rooibos field *vs.* natural vegetation (18.03 and 14.28 $mmol \cdot kg^{-1}$ respectively) and organic *vs.* conventional (14.04 and 21.57 $mmol \cdot kg^{-1}$ respectively) had higher P values due to the addition of rock phosphate at the beginning of each crop rotation (farmers, pers comm.) (Table 6).

The pH for the different locations (i.e. rooibos field and natural vegetation) of conventionally farmed sites differed significantly ($p = 0.008$) as did the pH in organically farmed sites ($p = 0.034$). For both organically and conventionally farmed sites, the pH in the rooibos fields was higher than that in the natural vegetation. This is however not unexpected since rooibos is a N_2-fixing legume, and recent studies indicate that nodulated rooibos plants can increase soil pH by up to 3.5 units as an adaptive strategy to overcome the adverse effects of low pH (Muofhe and Dakora, 2000). C and NO_3^- did not differ between conventional and organically farmed sites or between locations within each site ($p > 0.05$).

Table 6. Mean values of abiotic components across all sites during spring (Oct 2008). Values are means ± se of different locations as well as different farming types. Letters indicate

differences at the $p < 0.05$ level after a Student's t-test between paired locations (natural vegetation and rooibos fields, or between conventional and organic fields). Similar trends in wind speed and soil VWC were found at other sampling times (data not shown).

	Sites		Farming method	
	Natural vegetation	Rooibos field	Organic	Conventional
Wind speed ($m \cdot s^{-1}$)	2.04 ± 0.37^a	3.02 ± 0.34^b	2.84 ± 0.37^a	2.17 ± 0.37^a
Soil VWC (%)	8.50 ± 0.34^a	9.63 ± 1.06^a	8.72 ± 0.91^a	9.21 ± 0.60^a
Total N ($mmol \cdot kg^{-1}$)	24.82 ± 3.88^a	21.61 ± 2.14^a	29.46 ± 2.50^a	18.84 ± 1.33^b
Organic N ($mmol \cdot kg^{-1}$)	23.49 ± 3.85^a	20.49 ± 2.24^a	26.91 ± 2.89^a	17.08 ± 1.66^b
$NO3^-$ ($mmol \cdot kg^{-1}$)	0.07 ± 0.01^a	0.06 ± 0.01^a	0.07 ± 0.01^a	0.06 ± 0.00^a
$NH4^+$ ($mmol \cdot kg^{-1}$)	1.26 ± 0.31^a	1.05 ± 0.30^a	1.59 ± 0.21^a	0.80 ± 0.165^b
P ($mmol \cdot kg^{-1}$)	14.28 ± 1.68^a	18.03 ± 0.32^b	14.04 ± 1.14^a	21.57 ± 2.85^b
C ($mmol \cdot kg^{-1}$)	0.49 ± 0.10^a	0.29 ± 0.04^a	0.02 ± 0.00^a	0.03 ± 0.00^a
pH	4.19 ± 0.03^a	4.35 ± 0.03^b	4.36 ± 0.06^a	4.24 ± 0.04^a

Soil volumetric water content

Sites did not differ significantly in soil VWC ($p > 0.05$, $n = 195$) during spring. There was however, within site variation where four (sites 1, 6, 8 and 13) had a higher soil VWC in the rooibos field than in the natural vegetation and in two of these (site 6: $p < 0.001$; site 8: $p < 0.001$), the difference was almost 50% (Table 6, Fig. 11). The other two sites showing variation (site 5: $p < 0.001$; site 12: $p = 0.04$) had a higher soil VWC in the natural vegetation than in the rooibos field. Soil VWC did not differ during the remainder of the seasons at sites or locations (data not shown). No difference in soil VWC was found in rooibos fields with or without strips (spring: 8.32 and 9.34% respectively; similar results were found for data on other sampling times, data not shown).

As expected, the soil VWC varied between seasons in both organic and conventional sites ($p < 0.001$, organic: $n = 150$, conventional: $n = 240$, Table 7) while there was no within-site variation ($p > 0.05$, $n = 30$ per season,).

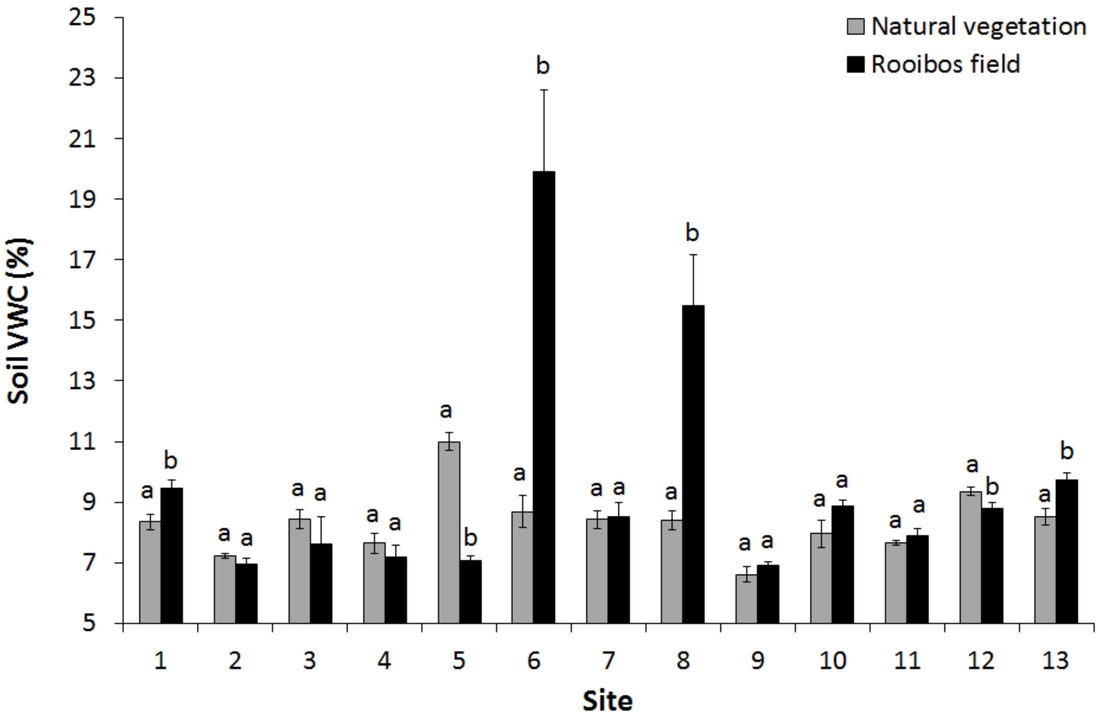

Fig. 11. Mean soil VWC of different locations (natural vegetation and rooibos fields) for all 13 sites during the rainy season (Jul to Sept). Values are means ± se of each location (n = 15) and letters indicate differences at the $p < 0.05$ level after a Student's t-test between paired locations.

Table 7. Mean soil VWC in different seasons grouped according to farming. Values are means ± se of 13 sites and letters indicate differences at the $p < 0.05$ level after a Student's t-test.

	Organic	**Conventional**
Spring		
Vegetation	7.67 ± 0.14^{a}	8.74 ± 0.14^{a}
Rooibos	7.44 ± 0.23^{a}	10.89 ± 0.55^{b}
Summer		
Vegetation	3.28 ± 0.07^{a}	3.76 ± 0.04^{a}
Rooibos	3.34 ± 0.05^{a}	3.71 ± 0.04^{a}
Autumn		
Vegetation	4.11 ± 0.03^{a}	4.02 ± 0.01^{a}
Rooibos	4.20 ± 0.05^{a}	3.99 ± 0.01^{b}

Temperature

Temperature was measured in summer and autumn on selected sites in all three locations (rooibos fields, vegetation and strips). No differences ($p > 0.05$) were found on the sites with strips present or absent (Fig. 12) or when comparing rooibos and natural vegetation (Fig. 13). The highest recorded temperature was 45°C and the lowest -2°C, both during autumn.

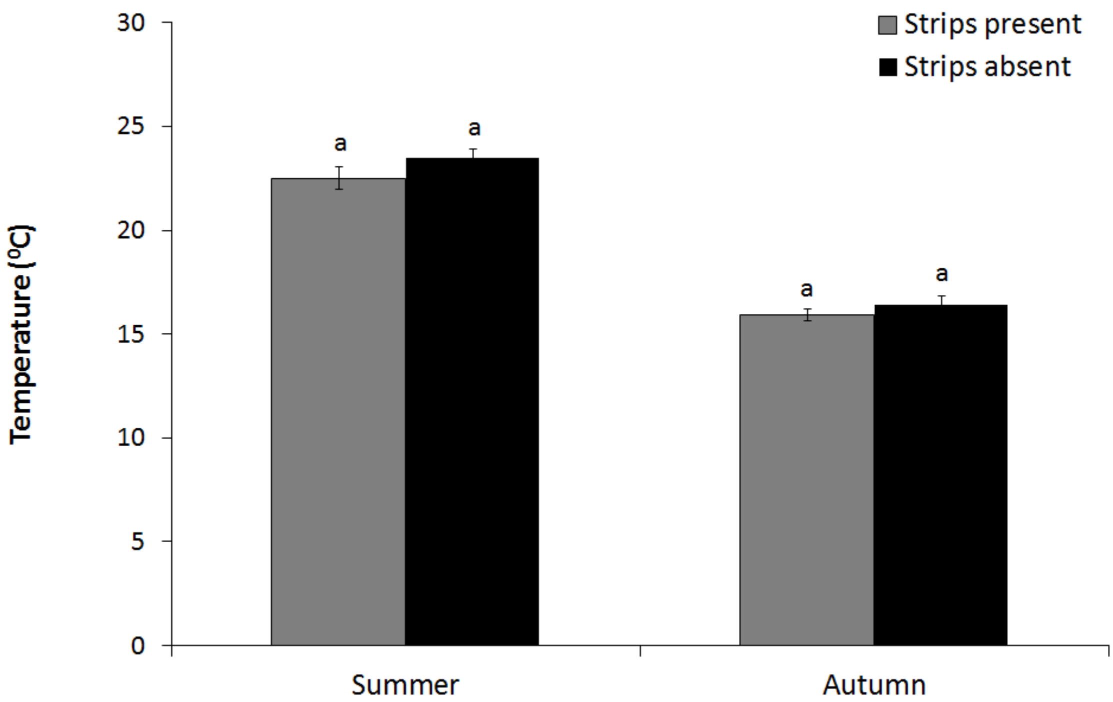

Fig. 12. Differences in mean temperatures across seasons for rooibos fields with strips present *vs*. rooibos fields with strips absent on all sites. Values are means ± se of four sites (sites 6, 9, 10 and 11). Different letters indicate a significant difference at the $p < 0.05$ level after a Student's t-test.

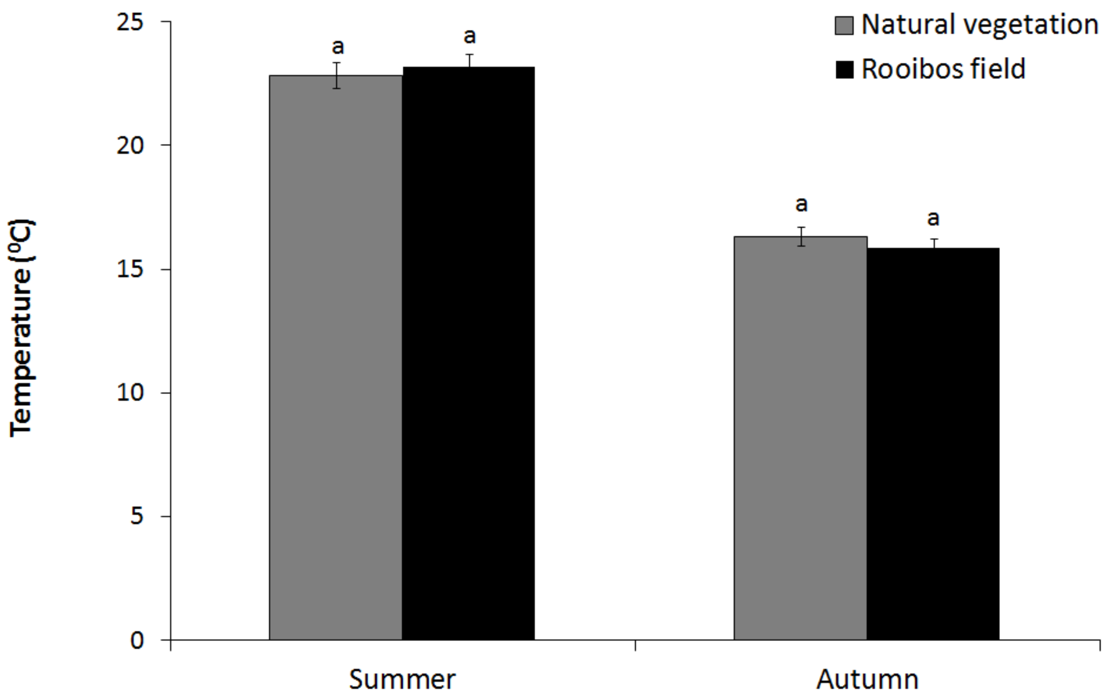

Fig. 13. Differences in mean temperatures across seasons for natural vegetation *vs*. rooibos fields on all sites. Values are means ± se of four sites (sites 6, 9, 10 and 11). Different letters indicate a significant difference at the p < 0.05 level after a Student's t-test.

Wind speed

Wind speed was measured across all seasons, but since the windy season is August to October for both Nieuwoudtville and Clanwilliam, this is the time of concern for rooibos producers. Since the other seasons showed similar trends, only the data from the windy season are presented here. Wind speeds were higher overall (Srep) in rooibos fields compared to the natural vegetation (3.02 ± 0.34 and 2.04 ± 0.37 $m{\cdot}s^{-1}$ respectively, $p < 0.001$, $n = 195$, Table 6). In agreement with this, where there were differences between locations within sites, these differences were always due to higher wind speeds in rooibos fields *vs*. the natural vegetation, and these difference were extreme at some sites, differing by two or more orders of magnitude (e.g. at sites 10 to 13 near Clanwilliam, Fig. 14).

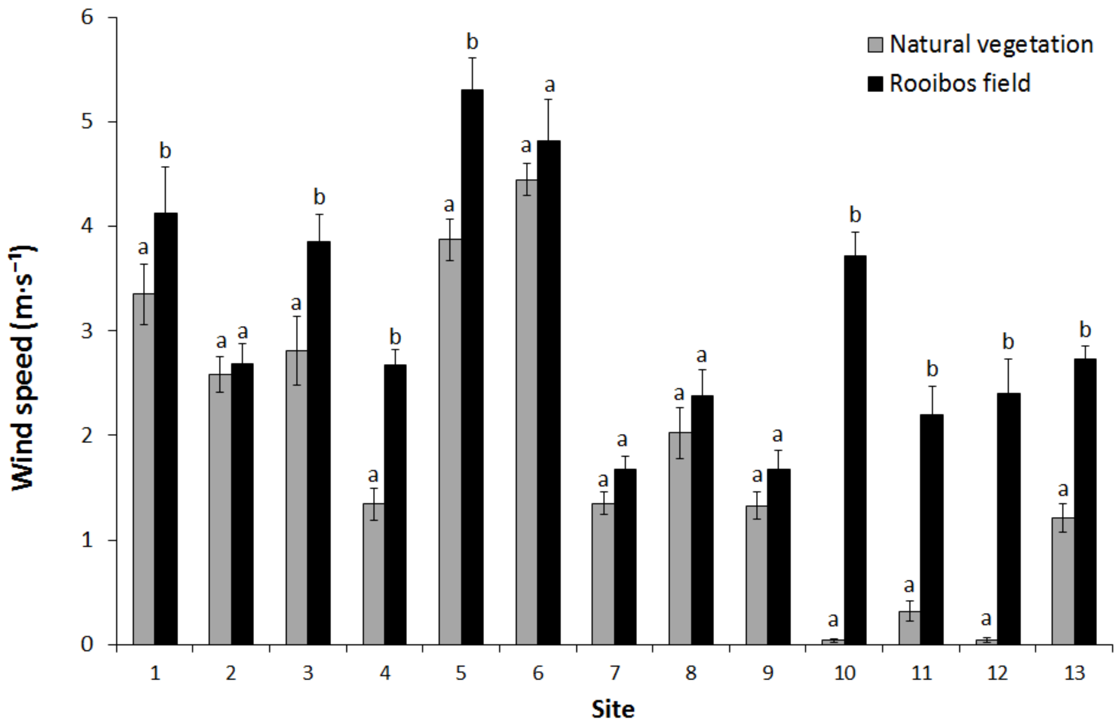

Fig. 14. Mean wind speed at different locations (natural vegetation and rooibos fields) for all 13 sites during the windy season (Aug to Oct). Values are means ± se of each location (n = 15) and letters indicate differences at the $p < 0.05$ level after a Student's t-test between paired locations and a Sequential Bonferroni was applied.

Sites were also compared in relation to the presence or absence of vegetation strips. Both sites with and without vegetation strips had higher overall wind speeds in the rooibos fields compared to the surrounding vegetation (Fig. 15), where sites 2, 3, 8, 9 and 11 had strips. However, the differences in wind speed between the locations were only significant in those sites without strips, indicating that the vegetation strips *do* act as barriers in decreasing wind speed in the rooibos fields (Fig. 15).

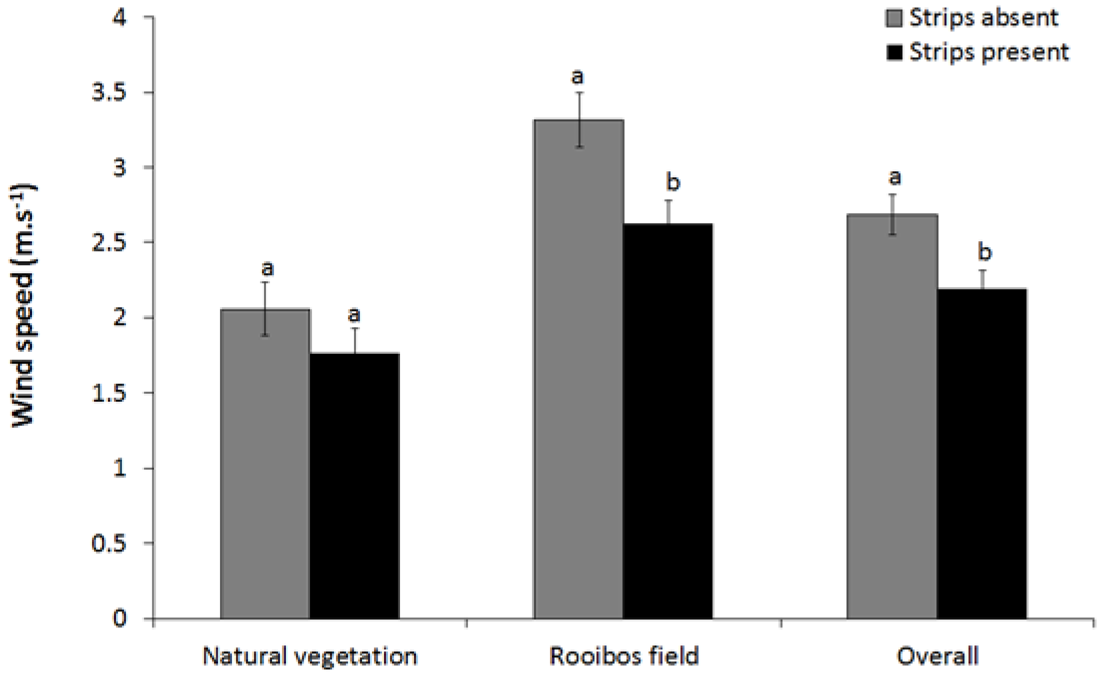

Fig. 15. Mean wind speed of different locations (natural vegetation and rooibos fields) for sites grouped according to strip presence in the field during the windy season (Aug to Oct). Values are means ± se of each group location and letters indicate differences at the $p < 0.05$ level after a Student's t-test between paired locations (natural vegetation and rooibos field). Overall, strip presence / absence differed significantly at $p < 0.001$ level.

Proximity to natural vegetation and some ecosystem services

The surrounding landscape of each site was characterised for each field within 500, 1000, and 3000 m radii (see Chapter 2) and the data were tested for correlations between percentage natural vegetation at each of these scales and soil nutrients, soil VWC, temperature and wind speed. The only significant correlations that could be drawn between proximity to natural vegetation and sites (Srep), were that of P. Soil P content increased as the proximity decreased ($r = 0.72$, $p = 0.02$). A significant correlation was, however, found for organically farmed sites where proximity to natural vegetation resulted in decreasing pH ($r = 0.92$, $p = 0.01$). Various other effects were tested but none were significant ($p > 0.05$, data not shown).

Discussion

Increasing proximity to natural vegetation in the form of strips resulted in decreased wind speeds on rooibos farms, thus acting as a windbreak and likely reducing soil erosion. Proximity to natural vegetation was correlated with increased pH in rooibos fields. In organically farmed sites the natural vegetation (both surrounding and proximity) did not seem to impact the ESS however, in conventionally farmed sites the proximity of the natural vegetation had an effect on P levels in the soil.

Farming practices (organic *vs.* conventional) differed in agrochemical use including fertilizer use, which affected total N, organic N, P and NH_4^+concentrations in the soil. Organic farms had higher total N and organic N but lower NH_4^+ than conventional farms. The higher P values are a likely result of fertilizer use and a reason why N values are lower in conventional sites. Higher P levels stimulates soil microbe activity which in turn immobilizes N into microbial structures, thus lowering the N levels in the soil (Raiesi and Ghollarata, 2006). Alternatively the N may be higher in organically farmed sites because of organic amendments (Jonasson *et al.*, 1996; Schimel and Weintraub, 2003), but this is not the case here. Thus organic rooibos farming tended to increase the organic N fraction (as is often the case in other farming sectors), which is associated with slower release of N_2O/losses of N from soil, as well as reduced Green House Gas emission (Cole *et al.*, 1997; Maljanen *et al.*, 2007).

Ultimately reduced organic N fractions could lead to increased dependence on agrochemicals and disruption of the ESS provided by the soil e.g. diversity and support of soil fauna. I found that, as various studies suggest, conventionally farmed sites have higher P levels than organically farmed sites (Mader *et al.*, 2002), but because conventionally farmed rooibos fields are often fertilized with about 20 to 50 $kg{\cdot}ha^{-1}$ P at planting, this is not unexpected. Indeed the increased P levels in conventionally farmed soils could also explain the reduced total N values, since P addition results in N immobilization into the microbial fraction (Marschner and Dell, 1994; Jeffries *et al.*, 2003).

In contrast to recent findings (Pimentel *et al.*, 2005), I did not find the C content (organic matter) to be higher in the organically farmed systems but rather similar between both organic and conventional systems. This could be due to reduced weeding in rooibos production practices, resulting in similar weed residues (remains of weeds that have been brush cut) being returned to the soil in organic and conventional farms. As mentioned above, the sampled organic rooibos sites did not generally make use of organic amendments and therefore it cannot be expected that soils on these organic farms would have increased soil organic matter (here measured as soil C). Studies show that a little variation in the soil pH is often found between sites with different farming practices (Mader *et al.*, 2002) and this is the case for the selected rooibos farmed sites.

Furthermore, I also found that in conventionally farmed sites the proximity of the natural vegetation had an effect on P levels in the soil. A lower P content was detected in areas where the rooibos fields were in close proximity to natural vegetation (whether surrounding or strips) with the P content increasing as the proximity decreased. This could indicate that the vegetation takes up P from rock phosphate fertilizer applied to rooibos fields at the beginning of the crop rotation (usually with oats). Proximity to natural vegetation had a similar effect on pH but this is expected since rooibos is known to increase the rhizosphere pH by up to 3.5 units when inoculated (Muofhe and Dakora, 2000). However, in our case, pH in both the rooibos field and natural vegetation were low, around 4, and the differences are unlikely to make any meaningful difference to plants adapted to acidic soils.

The VWC of the soil was not affected by strips or location but was significantly higher on conventionally farmed sites than organically farmed sites in two seasons. Although it was expected that organically farmed rooibos soils would have higher soil organic matter and thus increased soil water retention, the organic farms sampled did not extensively mulch or add other organic amendments to the soil that might increase soil water holding capacity. These results suggest that the removal of natural vegetation did not have a very major impact on the water drainage and runoff of the soils in spring (the rainy season). During the rest of the year, however, in the absence of non-crop species in the conventional fields, more water was supposedly available in the soil for the rooibos plants. As stated in the discussion on the flower resources of the sites (see Chapter 2), for both organic and conventional farming systems, the rooibos fields had a very high annual plant cover whilst the natural vegetation was dominated by perennials. This, together with the large amount of planted rooibos (as a perennial), suggests that plant cover was probably adequate, at least in spring, to reduce water runoff and allow water infiltration in both the farming systems.

Another aspect worth investigating is the higher wind speeds in rooibos fields compared to the natural vegetation, and the possible implications for soil VWC, particularly during the drier seasons. Water scarcity within rooibos fields in the drier seasons is exacerbated by both the lack of vegetation (floral) cover and wind. On sites 6 and 8, the soil VWC was significantly higher in the rooibos fields *vs.* the natural vegetation. This could be due to the very high rock cover in the natural vegetation (50%) on site 8 and the presence of a clay bank underneath a thin layer of sandy soil, resulting in a highly waterlogged rooibos field on site 6.

Temperature did not differ significantly between sites with and without strips nor between rooibos fields and natural vegetation. Shade provided by the perennials (including rooibos plants) could partly explain this. Since temperature was measured about 1 m above the soil (which is the approximate height of most Fynbos as well as rooibos plants), a difference might be obtained when the measurements are taken at a lower level in the vegetation. At a level lower than the predominant plant height, shade from the plants could possibly lead to lower temperatures in the natural vegetation compared to rooibos fields lacking this shade. This kind of temperature reduction is likely to be particularly important to young, establishing plants (usually < 30 cm in height). One way to test this would be to measure soil temperature, however limited data loggers did not allow for this. The lack of temperature difference could also be due to the cooling effect of the wind in the rooibos field which, as mentioned earlier, is significantly higher in the rooibos fields compared to the natural vegetation.

The main function of natural or semi-natural vegetation strips in rooibos fields at present seems to be to serve as wind breaks for young rooibos plants (plants < 30 cm) (and help provide resources for pollinators as well as other insects; see Chapter 2). Rooibos is replanted every six years and the vegetation strips thus only seem to serve a purpose for the farmers with every six year cycle. In recent years farmers have thus tended to leave less and less strips, i.e. ploughing and planting closer to the edges of the strips. We investigated the potential for these strips to also serve as wind breaks when the rooibos plants are bigger (> 30 cm) and to help reduce soil erosion during the windy season. We found that the wind speed was greatly reduced (as much as 100%) by the natural vegetation strips.

As expected, wind speed was negatively correlated with floral cover (as a measure of vegetation cover). Regarding the proportion of annuals and perennials in the fields, it seems that as perennial cover increased, wind speed dropped. Rooibos fields with not only annuals, but also perennials and bulbs will thus contribute to the reduction of soil erosion (and help provide resources for pollinators as well as other insects; see Chapter 2). It is therefore possible that reduced wind speed associated with natural vegetation strips inside the rooibos fields, leads to reduced soil erosion but this would have to be tested. It should be noted that in some cases the prevailing wind direction of a site was parallel to the vegetation strips. In these cases the vegetation strips could serve no purpose in reducing the wind speed or minimizing soil erosion and would explain the non-significant differences between sites with and without strips. Most farmers select strip direction to be perpendicular to the prevailing wind direction in the rooibos planting and yearly growth seasons. Wind direction during this season may or may not be the prevailing wind direction throughout the year. All of the windy Clanwilliam sites (sites 10 to 13) showed a significant difference in wind speed between the rooibos fields and natural vegetation (rooibos fields > 500 m radii).

No significant difference was found between the soil nutrients of farms with and without strips. This is possibly due to the nature and variation of the strips on the selected sites. These strips, although present, are in some cases reduced to only a meter or two wide (instead of 10 m, as recommended), often consisting of mulched dead Restionaceae species and are patchy, i.e. vegetation interlaced with parts consisting only of grasses. These types of strips, as well as those that consist of a narrow lane of Restionaceae and a few perennials with surrounding grass leading into the rooibos fields, lead to a marked edge effect[7] which also contribute to the loss of plant diversity in the strips. None of the sites investigated in this study had strips that truly represent the surrounding natural vegetation. In strips more functionally representative of the natural vegetation (i.e. including Fynbos indicator species such as Proteaceae, Ericaceae and Restionaceae), soil nutrient concentrations might well differ between rooibos fields with and without strips.

In conclusion, rooibos fields in close proximity to natural vegetation, either surrounding the fields or as strips within the fields, significantly reduce wind speeds inside rooibos fields. It is recommended that mechanical ploughing be limited either through brush cutting or leaving of vegetation strips since this allows for not only wind protection but also a higher survival of perennials and particularly bulbs, which are potential floral resources for pollinating insects.

References

ARCHER, E., CONRAD, J., MÜNCH, Z., OPPERMAN, D., TADROSS, M. & VENTER, J. 2009. Climate change, groundwater and intensive commercial farming in the semi-arid northern Sandveld, South Africa. *Journal of Integrative Environmental Sciences,* 6, 139 - 155.

BENGTSSON, J., AHNSTRÖM, J. & WEIBULL, A.-C. 2005. The effects of organic agriculture on biodiversity and abundance: A meta-analysis. *Journal of Applied Ecology,* 42, 261-269.

BENTON, T.G., VICKERY, J.A. & WILSON, J.D. 2003. Farmland biodiversity: is habitat heterogeneity the key? *Trends in Ecology and Evolution,* 18, 182-188.

[7] Edge effect refers to the juxtaposition of contrasting habitats. Where vegetation strips are placed inside rooibos fields without an extensive species composition and extended width, rooibos, grasses and weeds tend to encroach into these strips, rendering the strips disturbed vegetation. This encroachment and disturbance leads to further species loss due to the competitive advantage of the encroaching species.

BRAY, R.H. & KURTZ, L.T. 1945. Determination of total, organic, and available forms of phosphorus in soils. *Soil Science*, 59, 39-46.

BROQUET, C.A.M. 1992. The sedimentary record of the Cape Supergroup: A review. *In:* DE WIT, M.J. & RANSOME, I.G.D. (eds.) *Inversion tectonics of the Cape Fold Belt, Karoo and Cretaceous basins of Southern Africa.* Rotterdam, Netherlands: A.A. Balkema.

CABIN, R.J. & MITCHELL, R.J. 2000. To Bonferroni or not to Bonferroni: When and how are the questions. *Bulletin of the Ecological Society of America,* 81, 246-248.

COCKS, M.P. & STOCK, W.D. 2001. Field patterns of nodulation in fifteen Aspalathus species and their ecological role in fynbos vegetation in southern Africa. *Basic and Applied Ecology,* 2, 115-125.

COLE, C.V., DUXBURY, J., FRENEY, J., HEINEMEYER, O., MINAMI, K., MOSIER, A., PAUSTIAN, K., ROSENBERG, N., SAMPSON, N., SAUERBECK, D. & ZHAO, Q. 1997. Global estimates of potential mitigation of greenhouse gas emissions by agriculture. *Nutrient Cycling in Agroecosystems,* 49, 221-228.

DAILY, G.C. 1997. Introduction: What are ecosystem services? *In:* DAILY, G.C. (ed.) *Nature's Services: Societal dependence on natural ecosystems.* Washington, D.C: Island Press.

DAILY, G.C., MATSON, P.A. & VITOUSEK, P.M. 1997. Ecosystem services supplied by soil. *In:* DAILY, G. (ed.) *Nature's Services: Societal Dependence on Natural Ecosystem.* Washington, D.C.: Island Press.

DRINKWATER, L.E., LETOURNEAU, D.K., WORKNEH, F., VAN BRUGGEN, A.H.C. & SHENNAN, C. 1995. Fundamental differences between conventional and organic tomato agroecosystems in California. *Ecological Applications,* 5, 1098-1112.

HANSEN, T. 2006. Sustainable Rooibos Initiative: A sustainable production strategy for the South African rooibos tea industry. *Commissioned by the CapeNature Greater*

Cederberg Biodiversity Corridor (GCBC) and the South African Rooibos Council (SARC). Cape Town, South Africa.

HOLM, E. & DE MEILLON, E. 1995. *Pocket guide to insects of southern Africa.* Hartebeespoort: Ekogilde.

HOOPER, D.U. & VITOUSEK, P.M. 1997. The effects of plant composition and diversity on ecosystem processes. *Science*, 277 1302-1305.

JEFFRIES, P., GIANINAZZI, S., PEROTTO, S., TURNAU, K. & BAREA, J.-M. 2003. The contribution of arbuscular mycorrhizal fungi in sustainable maintenance of plant health and soil fertility. *Biology and Fertility of Soils*, 37, 1-16.

JONASSON, S., MICHELSEN, A., SCHMIDT, I.K., NIELSEN, E.V. & CALLAGHAN, T.V. 1996. Microbial biomass C, N and P in two arctic soils and responses to addition of NPK fertilizer and sugar: Implications for plant nutrient uptake. *Oecologia*, 106, 507-515.

LEDIEU, J., DE RIDDER, P., DE CLERCK, P. & DAUTREBANDE, S. 1986. A method of measuring soil moisture by time-domain reflectometry. *Journal of Hydrology*, 88, 319-328.

LINES, R. & HOWELL, R.S. 1963. *The use of flags to estimate the relative exposure of trial plantations.* London: H.M.Stat.Off.

MADER, P., FLIEßBACH, A., DUBOIS, D., GUNST, L., FRIED, P. & NIGGLI, U. 2002. Soil fertility and biodiversity in organic farming. *Science*, 296, 1694-1697.

MALJANEN, M., HYTONEN, J., MAKIRANTA, P., ALM, J., MINKKINEN, K., LAINE, J. & MARTIKAINEN, P. 2007. Greenhouse gas emissions from cultivated and aandoned organic croplands in Finland. *Boreal Environment Research*, 12, 133-140.

MARSCHNER, H. & DELL, B. 1994. Nutrient uptake in mycorrhizal symbiosis. *Plant and Soil,* 159, 89-102.

MATSON, P.A., PARTON, W.J., POWER, A.G. & SWIFT, M.J. 1997. Agricultural intensification and ecosystem properties. *Science,* 277, 504-509.

MICHENER, C.D. 2000. *The bees of the world.* Baltimore, Maryland, USA: The John Hopkins University Press.

MUOFHE, M.L. & DAKORA, F.D. 2000. Modification of rhizosphere pH by the symbiotic legume Aspalathus linearis growing in a sandy acidic soil. *Australian Journal of Plant Physiology,* 27, 1169-1173.

NELSON, D.W. & SOMMERS, L.E. 1986. Organic carbon. *In:* KLUTE, A. (ed.) *Methods of soil analysis: Part 2, Chemical and microbial properties.* 2nd ed. Madison, Wisconsin: American Society of Agronomy.

O'FARRELL, P.J., DONALDSON, J.S. & HOFFMAN, M.T. 2007. The influence of ecosystem goods and services on livestock management practices on the Bokkeveld plateau, South Africa. *Agriculture, Ecosystems and Environment,* 122, 312-324.

PEARS, N.V. 1968. The natural altitudinal limit of forest in the Scottish Grampians. *Oikos,* 19, 71-80.

PIMENTEL, D., HARVEY, C., RESOSUDARMO, P., SINCLAIR, K., KURZ, D., MCNAIR, M., CRIST, S., SHPRITZ, L., FITTON, L., SAFFOURI, R. & BLAIR, R. 1995. Environmental and economic costs of soil erosion and conservation benefits. *Science,* 267, 1117-1123.

PIMENTEL, D., HEPPERLY, P., HANSON, J., DOUDS, D. & SEIDEL, R. 2005. Environmental, energetic, and economic comparisons of organic and conventional farming systems. *Bioscience,* 55, 573-582.

PRETORIUS, G. 2008. Rooibos Biodiversity Initiative (RBI): Biodiversity best practice guidelines for the sustainable production of rooibos. *The South Africa Rooibos Council (SARC) in partnership with the CapeNature Greater Cederberg Biodiversity Corridor (GCBC) Project Management Unit.* Malmesbury, South Africa: Natura Libra Environmental Consultants.

PRETORIUS, G. 2010. Sustainability certification for the South African rooibos industry: Criteria and indicators. *The South Africa Rooibos Council (SARC).* Malmesbury, South Africa: Natura Libra Environmental Consultants.

RAICH, J.W. & SCHLESINGER, W.H. 1992. The global carbon dioxide flux in soil respiration and its relationship to vegetation and climate. *Tell'Us,* 44B, 81-99.

RAICH, J.W. & TUFEKCIOGLU, A. 2000. Vegetation and soil respiration: Correlations and controls. *Biogeochemistry,* 48, 71-90.

RAIESI, F. & GHOLLARATA, M. 2006. Interactions between phosphorus availability and an AM fungus (*Glomus intraradices*) and their effects on soil microbial resperation, biomass and enzyme activities in a calcareous soil. *Pedobiologia,* 50, 413-425.

REGANOLD, J.P., ELLIOTT, L.F. & UNGER, Y.L. 1987. Long-term effects of organic and conventional farming on soil erosion. *Nature,* 330, 370-372.

SCHIMEL, J.P. & WEINTRAUB, M.N. 2003. The implications of exoenzyme activity on microbial carbon and nitrogen limitation in soil: A theoretical model. *Soil Biology and Biochemistry,* 35, 549-563.

SILVERTOWN, J., DODD, M.E., GOWING, D.J.G. & MOUNTFORD, J.O. 1999. Hydrologically defined niches reveal a basis for species richness in plant communities. *Nature,* 400, 61-63.

STATSOFT INC. 2009. STATISTICA (data analysis software system). 9.0 ed. Tulsa, USA.

STEPHENSON, N.L. 1990. Climatic control of vegetation distribution: The role of the water balance. *American Naturalist*, 135, 649-670.

STOATE, C., BOATMAN, N.D., BORRALHO, R.J., CARVALHO, C.R., DE SNOO, G.R. & EDEN, P. 2001. Ecological impacts of arable intensification in Europe. *Journal of Environmental Management*, 63, 337-365.

VIVIAN-SMITH, G. 1997. Microtopographic heterogeneity and floristic diversity in experimental wetland communities. *Journal of Ecology*, 85, 71-82.

WALSH, B. 2004. Multiple comparisons: Bonferroni corrections and false discovery rates. *Lecture Notes.*

XIONG, S., JOHANSSON, M.E., HUGHES, F.M.R., HAYES, A., RICHARDS, K.S. & NILSSON, C. 2003. Interactive effects of soil moisture, vegetation canopy, plant litter and seed addition on plant diversity in a wetland community. *Journal of Ecology*, 91, 976-986.

Chapter 4

CONCLUSION AND RECOMMENDATIONS

Summary

This study was prompted by the pressure of demand to increase production of rooibos tea within a highly sensitive biodiversity hot spot. In order to increase the production, increasing amounts of natural vegetation are cleared in the sensitive rooibos production areas leading to habitat destruction and fragmentation. The primary aim of the study was to assess the contribution that natural vegetation made to ecosystem services (ESS) that support farming practices, and what measures might minimize the impact of rooibos farming on the environment. I assessed whether rooibos pollination is dependent on pollinators, particularly flying insects and then set out to test whether areas covered by natural vegetation (surrounding the farm or as vegetation strips) provided ESS (in the form of pollination, nutrient cycling, erosion prevention and temperature moderation) to rooibos production, and to test the influence of agrochemicals on these ESS by comparing organic and conventional farming of rooibos. I also assessed how rooibos seed-set is affected by proximity to natural vegetation, or the percentage of remaining natural vegetation in the surrounding environment. The final objective was to inform the Right Rooibos best practice guidelines regarding use of vegetation strips and amount of surrounding natural vegetation required to maximize provision of ESS.

The data presented in the foregoing chapters can be summarized as follows:

- Pollination efficiencies were 10 times higher in open bags *vs*. closed bags suggesting that rooibos relies to a great extent on flying insect pollinators.

- Abundance and diversity of bees and wasps increases with increased percentage of natural habitats/vegetation within landscapes at three different scales (i.e. radii of 500, 1000 and 3000 m).

- Abundance and diversity of bees and wasps within rooibos fields increases with increasing proximity to natural habitat, or the presence of (planted/natural vegetation) strips with an noted increase of up to 40% in fields closer than 500 m to natural vegetation;

- An increase of up to 200% in floral cover was found in organic (as opposed to conventional) rooibos fields which results in organic rooibos production areas having a higher abundance and diversity of bees and wasps;

- Organic farming practices, as opposed to conventional, resulted in 10 to 20% increased organic and total soil N concentrations and up to 40% decreased P in rooibos cultivated fields.

- Natural vegetation in close proximity to rooibos fields, whether as strips within fields or vegetation surrounding the field, was effective as wind breaks reducing wind speeds by up to two orders of magnitude in rooibos fields.

Conclusion

Little is known on the effects of landscape composition and farming practices on insect dynamics on different spatial scales, especially for rooibos. Kim *et al.* (2006) found that bee densities in sunflower fields respond to the amount of available natural habitats in the landscape scale (i.e. surrounding the fields) whereas Carvalheiro *et al.* (2010) found that pollination services decline in mango fields even with an abundance of natural vegetation surrounding the fields and that the field size (i.e. proximity to natural vegetation) is a more important factor for these services. Holzschuh (2006) on the other hand found that both these factors influence pollinator composition in wheat fields and that organic farming practices greatly enhance bee and wasp abundance and diversity . The results from this study conform to all of the above mentioned studies indicating that landscape composition, proximity to natural vegetation as well as farming practices influence rooibos pollinators. The implications of these findings for rooibos farmers are profound. Not only will field size and vegetation strip influence the abundance and diversity of rooibos pollinator, but will also affect rooibos seed-set. Furthermore, practicing organic management regimes will not only hold potential financial gains, but also enhance pollinator and other insect presence and thus seed set.

There is considerable evidence for the negative impacts of agricultural activities and agrochemical use on ESS delivered by natural vegetation (Kremen *et al.*, 2002; Kremen *et al.*, 2004; Holzschuh *et al.*, 2007). It is also well-known that agricultural activities such as ploughing, burning, and construction have a detrimental effect on the environment (Pimentel *et al.*, 1995; Mader *et al.*, 2002) and this is exacerbated in wind-blown areas with sandy soil such as in some rooibos production areas (Hansen, 2006; Pretorius, 2008; Archer *et al.*, 2009). This study provide further evidence, specifically for rooibos production areas, that vegetation strips reduce wind speed in rooibos fields, potentially reducing soil erosion. For rooibos farmers, this means that leaving natural vegetation strips inside rooibos fields will not only protect rooibos seedlings during planting season, but will also reduce soil erosion. Furthermore, by leaving more natural vegetation in and around rooibos fields, soil salinization will be reduced resulting in overall increased soil health.

Future research

The outcomes of this study provide input into the guidelines suggested in the Best Practice Guidelines for rooibos (Pretorius, 2008; 2010). Although as much natural vegetation surrounding fields as possible should be left, future studies should investigate the optimum amount to leave at different spatial scales in relation to different field sizes. Strips act as wind breaks in rooibos fields, but the optimal width, their spacing within fields, and species composition (if possible) of these strips in different rooibos production areas should also be investigated.

Rooibos is pollinated by flying insects, probably solitary bees and wasps as suggested by Gess and Gess (1994), but the exact pollinator species and the contribution to seed-set by these species should also be investigated. Once the exact species pollinating rooibos has been identified, a pollen study should be conducted on these insect species to determine which plant species these insects are using as floral resources when rooibos is not in flower.

Although the rooibos leaves and not the seeds are of commercial value to the farmer, local people collect the seeds from the rooibos fields. These seeds are then sold to farmers and nurseries which in turn provide the local workers with a source of income. Thus, although farmers may collect enough seed from the edge of rooibos fields for future crops, the local community will receive a greater income if seeds could also be collected from the middle of the fields. I suggest that this aspect is investigated in a future study in alliance with the social sciences.

A simplification in this study was made regarding farming practices, as sites were classified according to the application of agrochemicals into organic and conventional farming methods. But at present, the line between these methods is becoming more and more blurred. Agrochemicals can be organic and the fields where certain fertilizers are applied can still be considered organic. Also, organic farmers in this study were mostly organic by default, i.e. since no agrochemicals were used, and not due to specific soil conservation practices such as no-till or addition of organic amendments. Future studies should therefore focus more on the details and different aspects of farming methods and the different effects these aspects have on pollinators and surrounding vegetation.

Recommendations

- It is recommended to leave as much natural vegetation surrounding rooibos fields as possible since results from this study showed no leveling-off of insect abundance and diversity in a 500 to 3000 m radius around farms.

- Field size should ideally be less than 500 m from edge to middle as a marked decrease in insect abundance and diversity was found in fields with radii larger than 500 m. This in turn, could increase the pollination rate of rooibos flowers and thus potentially seed set.

- It is preferential to practice organic rooibos farming since greater numbers of insects were found within organic farms.

- It is recommended that mechanical ploughing be limited either through brush cutting or leaving of vegetation strips since this allows for not only wind protection but also a higher survival of perennials and particularly bulbs, which are potential floral resources for pollinating insects.

- Limited ploughing in rooibos fields will further result in increased insect presence and seed set as the nesting sites of potential pollinators would be less disturbed.

References

ARCHER, E., CONRAD, J., MÜNCH, Z., OPPERMAN, D., TADROSS, M. & VENTER, J. 2009. Climate change, groundwater and intensive commercial farming in the semi-arid northern Sandveld, South Africa. *Journal of Integrative Environmental Sciences,* 6, 139 - 155.

CARVALHEIRO, L.G., SEYMOUR, C.L., VELDTMAN, R. & NICOLSON, S.W. 2010. Pollination services decline with distance from natural habitat even in biodiversity-rich areas. *Journal of Applied Ecology*.

GESS, S.K. & GESS, F.W. 1994. Potential pollinators of the Cape Group of Crotalarieae (sensu Polhill) (Fabales: Papilionaceae), with implications for seed production in cultivated rooibos tea. *African Entomology,* 2, 97-106.

HANSEN, T. 2006. Sustainable Rooibos Initiative: A sustainable production strategy for the South African rooibos tea industry. *Commissioned by the CapeNature Greater Cederberg Biodiversity Corridor (GCBC) and the South African Rooibos Council (SARC).* Cape Town, South Africa.

HOLZSCHUH, A. 2006. *Bees and wasps in agricultural landscapes: Effects of dispersal corridors and land-use intensity at multiple spatial scales.*

HOLZSCHUH, A., STEFFAN-DEWENTER, I., KLEIJN, D. & TSCHARNTKE, T. 2007. Diversity of flower-visiting bees in cereal fields: Effects of farming system, landscape composition and regional context. *Journal of Applied Ecology,* 44, 41-49.

KIM, J., WILLIAMS, N.M. & KREMEN, C. 2006. Effects of cultivation and proximity to natural habitat on ground-nesting native bees in California sunflower fields. *Journal of the Kansas Entomological Society,* 79.

KREMEN, C., WILLIAMS, N.M., BUGG, R.L., FAY, J.P. & THORP, R.W. 2004. The area requirements of an ecosystem service: Crop pollination by native bee communities in California. *Ecology Letters,* 7, 1109-1119.

KREMEN, C., WILLIAMS, N.M. & THORP, R.W. 2002. Crop pollination from native bees at risk from agricultural intensification. *Proceedings of the National Academy of Sciences of the United States of America*, 99, 16812–16816.

MADER, P., FLIEßBACH, A., DUBOIS, D., GUNST, L., FRIED, P. & NIGGLI, U. 2002. Soil fertility and biodiversity in organic farming. *Science*, 296, 1694-1697.

PIMENTEL, D., HARVEY, C., RESOSUDARMO, P., SINCLAIR, K., KURZ, D., MCNAIR, M., CRIST, S., SHPRITZ, L., FITTON, L., SAFFOURI, R. & BLAIR, R. 1995. Environmental and economic costs of soil erosion and conservation benefits. *Science,* 267, 1117-1123.

PRETORIUS, G. 2008. Rooibos Biodiversity Initiative (RBI): Biodiversity best practice guidelines for the sustainable production of rooibos. *The South Africa Rooibos Council (SARC) in partnership with the CapeNature Greater Cederberg Biodiversity Corridor (GCBC) Project Management Unit.* Malmesbury, South Africa: Natura Libra Environmental Consultants.

PRETORIUS, G. 2010. Sustainability certification for the South African rooibos industry: Criteria and indicators. *The South Africa Rooibos Council (SARC).* Malmesbury, South Africa: Natura Libra Environmental Consultants.

Appendix A

FLORAL LISTS FOR ALL SEASONS

The following tables present the presence of floral species for each season: spring (Sept 2008), summer (Dec 2008) and autumn (Mar 2009). For each site the presence of a species is indicated by a 1.

Sept 2008

Family	Species	Authority	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7	SITE 8	SITE 9	SITE 10	SITE 11	SITE 12	SITE 13
Aizoaceae	Adenogramma glomerata	(L.f.) Druce		1	1			1	1	1	1	1	1	1	1
Rutaceae	Agathosma capensis	(L.) Dummer										1			
Rubiaceae	Anthospermum aethiopicum	L.							1						
Rubiaceae	Anthospermum spathulatum	Spreng.								1					
Aizoaceae	Apatesia helanthoides	(Aiton) N.E. Br.										1		1	
Asteraceae	Arctotis auriculata	Jacq.											1	1	1
Asteraceae	Arctotis fastuosa	Jacq.				1									
Fabaceae	Aspalathus linearis	(Burm. F.) T. Dahlgren		1	1	1	1	1	1	1	1	1	1	1	1
Fabaceae	Aspalathus spinescens	Thunb.		1											
Iridaceae	Babiana sambucina	(Jacq.) Ker Gawl.							1						
Asteraceae	Chrysocoma ciliata	L.							1			1			1
Asteraceae	Chrysocoma oblongifolia	DC.				1									
Aizoaceae	Conicosia elongata	(Haw.) N.E. Br.												1	
Orchidaceae	Corycium crispum	(Thunb.) Sw.								1					
Asteraceae	Cotula barbata	DC.	1		1	1	1	1	1	1	1		1		
Asteraceae	Cotula spp	L.												1	
Crassulaceae	Crassula alpestris	Thunb.	1				1	1							
Crassulaceae	Crassula atropurpurea var. watermeyeri	(Compton) Toelken									1				
Scrophulariaceae	Cromidon varicalyx	Hilliard											1		
Scrophulariaceae	Diascia maculata	K.E. Steiner								1					
Asteraceae	Dimorphotheca pluvialis	(L.) Moench										1	1	1	
Asteraceae	Dimorphotheca sinuata	DC.		1			1					1			
Asteraceae	Dimorphotheca tragus	(Aiton) B. Nord.											1		
Rutaceae	Diosma ramosissima	Bartl. & H.L. Wendl.				1	1		1		1				
Scrophulariaceae	Dischisma spicatum	(Thunb.) Choisy		1			1								

Sept 2008 (cont.)															
Family	**Species**	**Authority**	**SITE 1**	**SITE 2**	**SITE 3**	**SITE 4**	**SITE 5**	**SITE 6**	**SITE 7**	**SITE 8**	**SITE 9**	**SITE 10**	**SITE 11**	**SITE 12**	**SITE 13**
Aizoaceae	Drosanthemum spp	Schwantes								1					
Euphorbiaceae	Euphorbia mauritanica	L.										1			
Asteraceae	Euryops speciosissimus	DC.										1			
Asteraceae	Euryops tenuissimus	(L.f.) DC.					1								
Asteraceae	Felicia dubia	Cass.	1												
Asteraceae	Felicia filifolia	(Vent.) Burtt Davy	1												
Asteraceae	Felicia tenella	(L.) Nees			1			1	1	1	1	1	1		
Rubiaceae	Galium capense subsp. namaquense	(Eckl. & Zeyh.) Puff													1
Iridaceae	Gladiolus alatus	L.		1											
Iridaceae	Gladiolus speciosus	Thunb.								1					
Asteraceae	Gorteria diffusa	Thunb.								1					
Asteraceae	Gymnodiscus capillaris	(L.f.) DC.		1				1	1	1					
Scrophulariaceae	Hebenstretia dentata	L.								1	1	1	1	1	
Scrophulariaceae	Hebenstretia pariflora	E. Mey.												1	
Scrophulariaceae	Hebenstretia robusta	E. Mey.			1										
Asteraceae	Helichrysum moeserianum	Thell.		1	1	1	1	1	1			1	1	1	1
Brassicaceae	Heliophila acuminata	(Eckl. & Zeyh.)	1	1	1				1	1	1	1	1	1	
Brassicaceae	Heliophila carnosa	(Thunb.) Steud.				1									
Scrophulariaceae	Hemimeris racemosa	(Houtt.) Merrill											1		
Malvaceae	Hermannia alnifolia	L.					1								
Malvaceae	Hermannia muricata	Eckl. & Zeyh.										1			
Malvaceae	Hermannia trifurca	L.											1		
Fabaceae	Indigofera heterophylla	Thunb.	1					1							
Hyacinthaceae	Lachanalia elegans	W.F. Barker	1		1	1					1				1
Hyacinthaceae	Lachenalia unifolia	Jacq.											1		

Sept 2008 (cont.)

Family	Species	Authority	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7	SITE 8	SITE 9	SITE 10	SITE 11	SITE 12	SITE 13
Iridaceae	Lapeirousia fabricii	(D. Delaroche) Ker Gawl.													1
Iridaceae	Lapeirousia jacquinii	N.E. Br.						1							
Asteraceae	Lasiospermum brachyglossum	DC.										1	1	1	1
Asteraceae	Leysera gnaphalodes	(L.) L.			1				1						
Linaceae	Linum africanum	L.										1			
Boraginaceae	Lobostemon laevigatus	Levyns							1						
Fabaceae	Lupinus spp	L.												1	
Rutaceae	Macrostylis squarrosa	Bartl. & H.L. Wendl.					1	1	1						
Asteraceae	Metalasia fastigiata	(Thunb.) D. Don	1												
Apocynaceae	Microloma sagittatum	(L.) R. Br.				1									1
Polygalaceae	Muraltia heisteria	(L.) DC.													1
Polygalaceae	Muraltia spinosa	(L.) F. Forest & J.C. Manning					1			1					1
Polygalaceae	Muraltia spp	DC.										1			
Scrophulariaceae	Nemesia anisocarpa	Benth.											1	1	
Scrophulariaceae	Nemesia bicornis	(L.) Pers.											1		
Scrophulariaceae	Nemesia spp	Vent.										1			
Asteraceae	Oedera squarrosa	(L.) Anderb. & Bremer	1				1		1		1				
Asteraceae	Oncosiphon grandiflorum	(Thunb.) Källersjö											1		
Hyacinthaceae	Ornithogalum cooperi	(Baker) J.C. Manning & Goldblatt										1			1
Hyacinthaceae	Ornithogalum maculatum	Jacq.	1												
Hyacinthaceae	Ornithogalum namaquense	(Baker) J.C. Manning & Goldblatt													1
Asteraceae	Osteospermum pinnatum	(Thunb.) Norl.								1					
Asteraceae	Othonna spp	L.												1	
Oxalidaceae	Oxalis obtusa	Jacq.			1				1		1				
Oxalidaceae	Oxalis purpurea	L.												1	

Sept 2008 (cont.)															
Family	**Species**	**Authority**	**SITE 1**	**SITE 2**	**SITE 3**	**SITE 4**	**SITE 5**	**SITE 6**	**SITE 7**	**SITE 8**	**SITE 9**	**SITE 10**	**SITE 11**	**SITE 12**	**SITE 13**
Thymelaeaceae	Passerina glomerata	Thunb.										1		1	
Geraniaceae	Pelargonium coronopifolium	Jacq.							1						
Geraniaceae	Pelargonium grandiflorum	(Andr.) Willd.											1	1	
Rhamnaceae	Phylica cephalantha	Sond.			1	1									
Rhamnaceae	Phylica pulchella	Schltr.						1							
Rhamnaceae	Phylica rigidifolia	Sond.					1	1	1			1		1	
Scrophulariaceae	Polycarena batteniana	Hilliard			1					1					1
Proteaceae	Protea laurifolia	Thunb.	1												
Brassicaceae	Raphanus raphanistrum	L.											1	1	1
Asteraceae	Rhynchopsidium pumilium	(L.f.) DC.				1				1		1			
Polygonaceae	Rumex lativalvis	Meisn.												1	1
Aizoaceae	Ruschia extensa	L. Bolus			1										
Aizoaceae	Ruschia goodiae	L. Bolus										1			
Aizoaceae	Ruschia robusta	L. Bolus									1				
Gentianaceae	Sebaea exacoides	(L.) Schinz	1				1	1	1						1
Gentianaceae	Sebaea pusillia	Eckl. ex. Cham.		1											
Scrophulariaceae	Selago glabrata	Choisy								1					
Scrophulariaceae	Selago glutinosa	E. Mey.						1							
Asteraceae	Senecio abruptus	Thunb.	1						1						
Asteraceae	Senecio arenarius	Thunb.											1		
Asteraceae	Senecio cakilefolius	DC.			1	1	1	1	1						
Asteraceae	Senecio carroensis	DC.					1								
Asteraceae	Senecio elegans	L.								1	1	1			1
Asteraceae	Senecio erosus	L.f.	1												
Asteraceae	Senecio spp	L.												1	

Sept 2008 (cont.)

Family	Species	Authority	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7	SITE 8	SITE 9	SITE 10	SITE 11	SITE 12	SITE 13
Proteaceae	Serruria fucifolia	Salisb. ex Knight											1		
Solanaceae	Solanum giftbergense	Dunal													1
-	Species 1	-	1												
-	Species 2	-	1												
-	Species 3	-	1												
-	Species 4	-	1												
-	Species 5	-	1												
-	Species 6	-	1												
-	Species 7	-		1											
-	Species 8	-			1										
-	Species 9	-			1										
-	Species 10	-				1									
-	Species 11	-				1									
-	Species 12	-				1									
-	Species 13	-				1									
-	Species 14	-						1							
-	Species 15	-						1							
-	Species 16	-							1						
-	Species 17	-							1						
-	Species 18	-							1						
-	Species 19	-								1	1				
-	Species 20	-								1	1		1	1	
-	Species 21	-								1					
-	Species 22	-								1					
-	Species 23	-									1				

Sept 2008 (cont.)

Family	Species	Authority	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7	SITE 8	SITE 9	SITE 10	SITE 11	SITE 12	SITE 13
-	Species 24	-									1				
-	Species 25	-									1				
-	Species 26	-											1		
-	Species 27	-												1	
-	Species 28	-													1
-	Species 29	-													1
-	Species 31	-										1			
Asteraceae	Taraxacum officinale	Weber											1	1	
Aizoaceae	Tetragonia fruticosa	L.				1									
Aizoaceae	Tetragonia spp	L.													1
Asphodelaceae	Trachyandra muricata	(L.f.) Kunth										1		1	1
Asteraceae	Ursinia anthemoides	(L.) Poir.		1	1	1	1	1	1	1	1	1			1
Asteraceae	Ursinia cakilefolia	DC.	1	1											
Asteraceae	Ursinia nudicaulis	(Thunb.) N.E. Br.				1									
Campanulaceae	Wahlenbergia androsacea	A. DC.		1											
Campanulaceae	Wahlenbergia annularis	A. DC.													1
Scrophulariaceae	Zaluzianskya affinis	Hilliard										1			
Scrophulariaceae	Zaluzianskya peduncularis	(Benth.) Walp.							1						

Dec 2008

Family	Species	Authority	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7	SITE 8	SITE 9	SITE 10	SITE 11	SITE 12	SITE 13
Fabaceae	Aspalathus linearis	(Burm. F.) T. Dahlgren	1			1	1	1					1		1
Asteraceae	Chrysocoma ciliata	L.	1	1	1	1	1	1	1					1	
Convolvulaceae	Convolvulus capensis	Burm.f.			1		1								
Asteraceae	Helichrysum cylindriflorum	(L.) Hillard & B.L. Burtt	1												
Asteraceae	Helichrysum moeserianum	Thell.	1	1	1	1	1	1	1	1	1	1	1	1	1
Asteraceae	Leysera gnaphalodes	(L.) L.		1					1						
Asteraceae	Oedera squarrosa	(L.) Anderb. & Bremer	1												
Asteraceae	Oncosiphon grandiflorum	(Thunb.) Källersjö		1		1									
Proteaceae	Paranomus bracteolaris	Knight	1												
Rhamnaceae	Phylica spp	L.	1											1	
Asteraceae	Pteronia incana	(Burm.) DC.			1										1

Mar 2008															
Family	**Species**	**Authority**	**SITE 1**	**SITE 2**	**SITE 3**	**SITE 4**	**SITE 5**	**SITE 6**	**SITE 7**	**SITE 8**	**SITE 9**	**SITE 10**	**SITE 11**	**SITE 12**	**SITE 13**
Rutaceae	Agathosma capensis	(L.) Dummer								1					
Rubiaceae	Anthospermum spp	L.							1						
Fabaceae	Aspalathus linearis	(Burm. F.) T. Dahlgren	1												
Asteraceae	Chrysocoma spp	L.								1					
Asteraceae	Chrysocoma ciliata	L.	1				1	1	1	1					
Rutaceae	Diosma acmaeophylla	Eckl. & Zeyh.							1						
Rutaceae	Diosma hirsuta	L.								1	1				
Amaryllidaceae	Haemanthus spp	L.						1							
Asteraceae	Helichrysum moeserianum	Thell.		1	1	1	1	1	1	1	1				
Asteraceae	Leysera gnaphalodes	(L.) L.	1						1						
Asteraceae	Metalasia muricata	(L.) D. Don							1						
Asteraceae	Stoebe fusca	(L.) Thunb.						1			1				1
-	Species 30	-								1					